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Form A. *(Membership Application)*

INSTITUTE OF METALS.

Founded 1908. *Incorporated* 1910.

To the Secretary,

    I, the undersigned..., being of the required age and desirous of becoming a.................................Member of the INSTITUTE OF METALS, agree that I will be governed by the regulations of the Association as they are now formed, or as they may be hereafter altered, and that I will advance the interests of the Association as far as may be in my power ; and we, the undersigned, from our personal knowledge, do hereby recommend him for election.

Name in full...

Address...

Business or Profession...

Qualifications..

....

Signature..

Dated this....................day of...................................., 191 .

.... }
.... } Signatures of three Members
.... }

    The Council, having considered the above recommendation,

present Mr....................................to be Balloted for as a..................... | To be filled up by the Council

Member of the INSTITUTE OF METALS.

....

36 VICTORIA STREET,   *Chairman.*

    WESTMINSTER, LONDON, S.W. 1.

Dated this..........................*day of*...........................191......

    FOR QUALIFICATIONS OF MEMBERS, SEE SECTION I. OTHER SIDE.

    (*It would be a convenience if the Candidate's Card were sent with this form.*)

XVII.

EXTRACTS FROM THE RULES.

(MEMORANDUM AND ARTICLES OF ASSOCIATION.)

SECTION I.—CONSTITUTION.

Rule 4.—Members of the Association shall be either Honorary Members, Fellows, Ordinary Members, or Student Members.

Rule 5.—*Ordinary Members* shall be more than twenty-three years of age, and shall be persons occupying responsible positions. They shall be—
    either (*a*) persons engaged in the manufacture, working, or use of non-ferrous metals and alloys ;
    or (*b*) persons of scientific, technical, or literary attainments connected with or interested in the metal trades or with the application of non-ferrous metals and alloys.

Student Members shall be more than seventeen years of age, and shall not remain Student Members of the Association after they are twenty-five years of age, and shall be—
    either (*a*) Students of Metallurgy ;
    or (*b*) pupils or assistants of persons qualified for ordinary membership whether such persons are actually members of the Association or not.

Student Members shall not be eligible for election on the Council nor entitled to vote at the Meetings of the Association.

SECTION II.—ELECTION OF MEMBERS.

Rule 6.—Applications for membership shall be in writing in the form marked " A," and such application must be signed by the applicant and not less than three members of the Association.

Rule 7.—Such applications for membership as Ordinary Members or Student Members as are approved by the Council shall be inserted in voting lists. These voting lists will constitute the ballot papers, and will specify the name, occupation, address, and proposers of each candidate. They shall be forwarded to the members for return to the Secretary at a fixed date, and four-fifths of the votes recorded shall be necessary for the election of any person.

Every such election shall be subject to the payment by the applicant of his entrance fee and first annual subscription, and he shall not become a member of the Association nor be entered on the Register of Members until such sums are actually received from him. In the event of his failing to pay such sums within the time specified in the notification to him of his election, his election shall be void.

Rule 8.—Upon election under the preceding Article the Secretary shall forward to the applicant so elected notice thereof in writing in the form marked " B."

Rule 9.—In the case of non-election, no mention thereof shall be made in the minutes.

SECTION VI.—SUBSCRIPTIONS.

Rule 28.—The subscription of each Ordinary Member shall be two guineas per annum, and of each Student Member one guinea per annum. Ordinary Members shall pay an entrance fee of two guineas each, and Students an entrance fee of one guinea each.

Rule 29.—Subscriptions shall be payable in advance on July 1st in each year, save in the case of Ordinary Members and Student Members elected under Clauses 6 and 7 hereof, whose entrance fee and annual subscription shall become payable in accordance with the notification to them of their election. Every subscription shall cover the period down to the 30th of June next following, and no longer.

Rule 30.—Subject to the provisions of Clause 7 hereof, any member whose subscription shall be six months in arrear, shall forfeit temporarily all the privileges of the Association. Due notice on the form following marked " C " shall be given to such member, and if such subscription remains unpaid upon the date specified for payment in this notice, the Council may remove such member from the Register of Members of the Association, and thereupon any member whose name is so removed shall cease to be a member thereof, but shall nevertheless remain liable to the Association for such arrears.
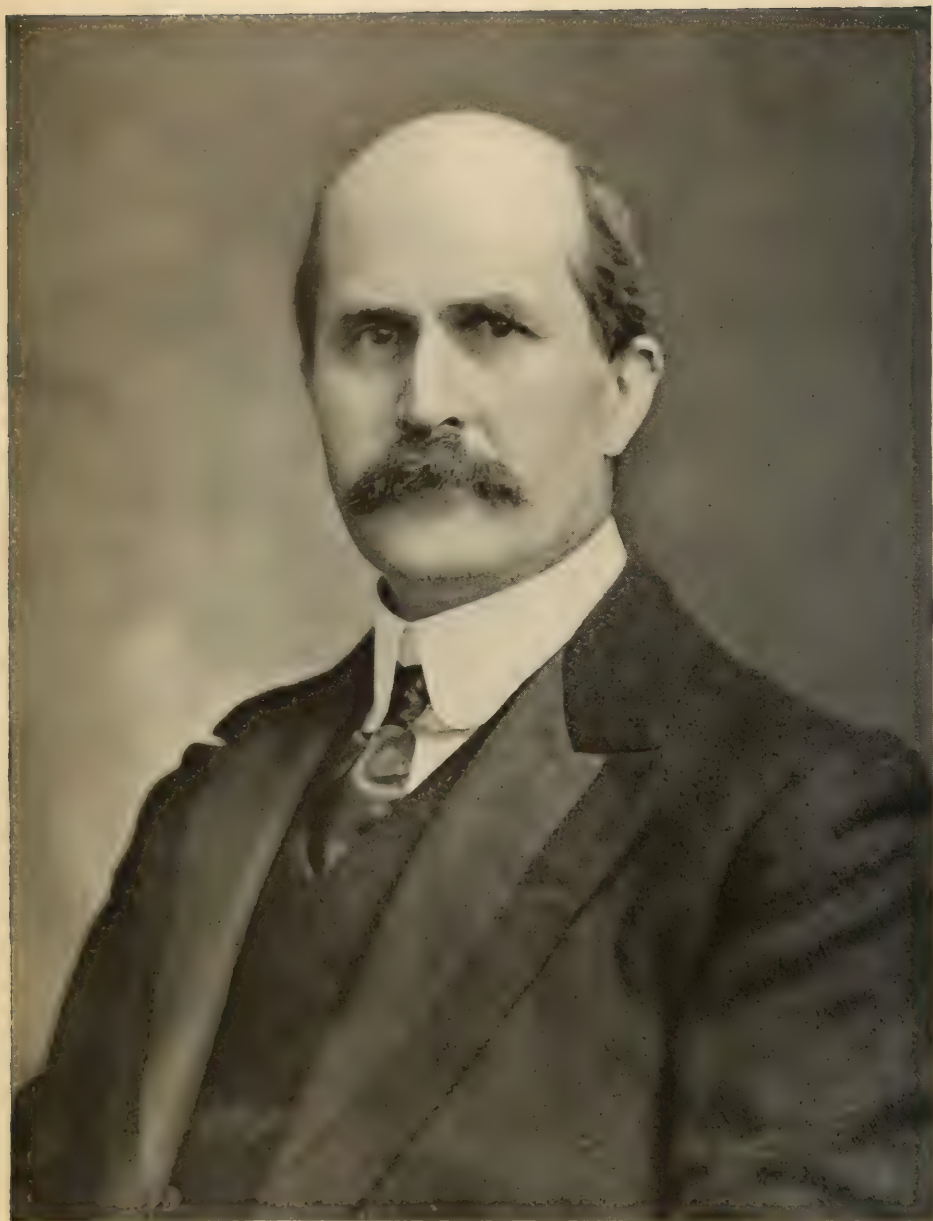
Professor W. H. BRAGG, F.R.S.,

MAY LECTURER, 1916.

(For May Lecture, see " Journal," Vol. XVI.)

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THE INSTITUTE OF METALS

President.

Sir GEORGE BEILBY, LL.D., F.R.S., Glasgow.

Past-Presidents.

Sir GERARD MUNTZ, Bart., Birmingham.
Professor W. GOWLAND, F.R.S., A.R.S.M., London.
Professor A. K. HUNTINGTON, A.R.S.M., London.
Engineer Vice-Admiral Sir HENRY ORAM, K.C.B., F.R.S., London.

Vice-Presidents.

G. A. BOEDDICKER.	Birmingham.
Professor H. C. H. CARPENTER, M.A., Ph.D., A.R.S.M.	London.
J. T. MILTON.	London.
Sir THOMAS ROSE, D.Sc.	London.
L. SUMNER, M.Sc.	Manchester.
Professor T. TURNER, M.Sc., A.R.S.M.	Birmingham.

Honorary Treasurer.

A. E. SEATON	London.

Members of Council.

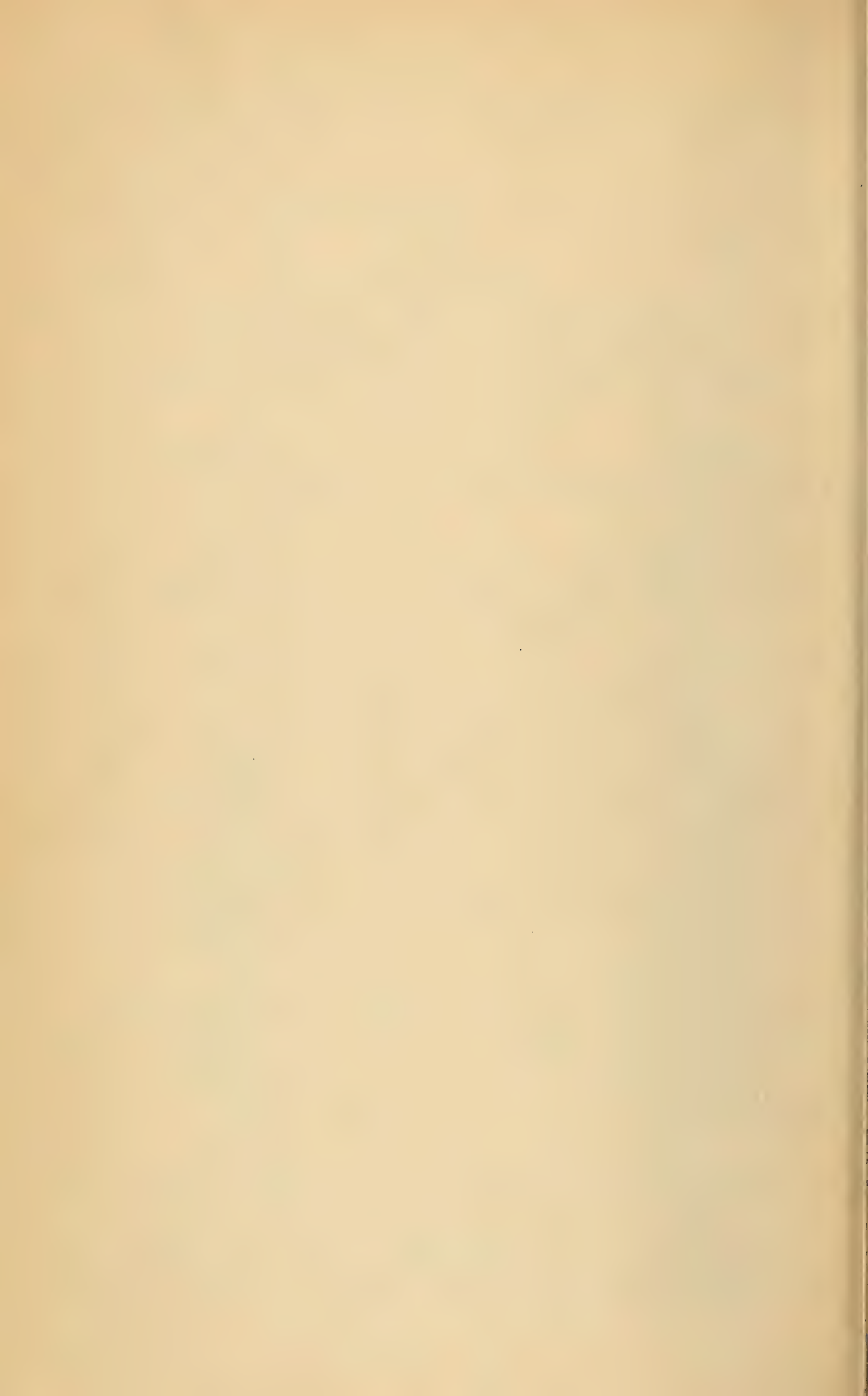|	
W. H. ALLEN	Bedford.
L. ARCHBUTT.	Derby.
G. BEAN	Birmingham.
A. CLEGHORN	Glasgow.
J. DEWRANCE	London.
S. EVERED	Birmingham.
Sir ROBERT HADFIELD, Bart., F.R.S.	Sheffield.
G. HUGHES	Horwich.
R. S. HUTTON, D.Sc.	Sheffield.
W. MURRAY MORRISON	London.
The Hon. Sir CHARLES PARSONS, K.C.B., F.R.S.	Newcastle-on-Tyne.
ARNOLD PHILIP, B.Sc., A.R.S.M.	Portsmouth.
W. ROSENHAIN, D.Sc., F.R.S.	Teddington.
Sir W. E. SMITH, C.B.	London.
Sir WILLIAM WEIR.	Glasgow.

Hon. Auditor.	Secretary.
G. G. POPPLETON, F.C.A., Birmingham.	G. SHAW SCOTT, M.Sc.

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SECTION II.—ABSTRACTS OF PAPERS RELATING TO THE NON-FERROUS METALS AND THE INDUSTRIES CONNECTED THEREWITH.

THE INSTITUTE OF METALS

SECTION I.

MINUTES OF PROCEEDINGS.

ANNUAL GENERAL MEETING.

THE ANNUAL GENERAL MEETING of the Institute of Metals was held in the Rooms of the Chemical Society, Burlington House, Piccadilly, London, W., on Wednesday and Thursday, March 21 and 22, 1917, Sir George Beilby, F.R.S., LL.D., President, in the Chair.

The SECRETARY (Mr. G. Shaw Scott, M.Sc.) read the Minutes of the previous Meeting, held on Wednesday, September 20, 1916, in the Rooms of the Chemical Society, which were found to be a correct record and were signed by the Chairman.

REPORT OF COUNCIL.

IT is with much satisfaction that the Council report that considerable progress has been made by the Institute during the past year. Not only has the membership developed substantially and the financial position improved, but the usefulness of the Institute to the country in the present time of national emergency, as well as its international status, has also increased. Particularly noteworthy has been the setting up of research laboratories in connection with the work of the Corrosion Research Committee as a result of financial assistance afforded by the Government.

THE ROLL OF THE INSTITUTE.

The number of Members on the roll of the Institute on December 31, 1916, was as follows :

Honorary Members	4
Ordinary Members	648
Student Members	8
Total	660

The following table shows the changes in the membership that have taken place during the past five years :

	Dec. 31, 1912.	Dec. 31, 1913.	Dec. 31, 1914.	Dec. 31, 1915.	Dec. 31, 1916.
Fellows	1	...	...	...	...
Honorary Members . .	4	3	3	2	4
Ordinary Members . .	578	604	628	628	648
Student Members . .	23	19	14	10	8
Total . . .	606	626	645	640	660

The Council are glad to record the election to Honorary Membership of Professor Sir William Crookes, Kt., O.M., Past-Pres. R.S., LL.D., and Sir J. J. Thomson, Kt., O.M., D.Sc., Pres. R.S.

The total of 660 has been arrived at after the removal from the Register of the names of 18 members of enemy nationality, thus making the increase of 20 during the past year all the more noteworthy. There were elected 49 Members and 3 Student Members during the past year, the former including the first lady member. An analysis of the nationality of the members elected during the past year shows that Great Britain contributed 35 Members ; United States of America, 8 ; Russia, 2 ; Italy, 2 ; France, Holland, and Japan, 1 each. With regard to towns, London contributed 16 new Members ; Glasgow, 3 ; Huddersfield, Manchester, Newcastle-on-Tyne, and Sheffield, 2 each ; eight other towns contributing 1 each. The 648 Ordinary and 8 Student Members include 59 members on active service, as well as 8 Belgians. A list of the members on active service is included in the Journal, Vol. XVI. Sergeant S. C. Giggins, of the Institute's staff, is serving in Mesopotamia

The Council have to record with regret the deaths of Mr. H. H. Aston, Mr. C. A. Collie, and Mr. W. Gemmell, as well as Captain W. Morton Johnson and Engineer-Commander R. Main, the two latter being killed in action.

General Meetings.

During the year 1916 three General Meetings have been held. The Annual General Meeting took place in London on March 29, when the

newly-elected President, Dr. G. T. Beilby, F.R.S., occupied the chair, and delivered his Inaugural Address. The following papers were subsequently read and discussed :

1. " The Electrolytic Method of Preventing Corrosion." By ELLIOTT CUMBER-LAND (London).
2. Third Report to the Corrosion Committee. By W. E. GIBBS, M.Sc., R. H. SMITH, and G. D. BENGOUGH, D.Sc., M.A. (Liverpool).
3. " The Transformations in Alloys of Gold with Copper." By N. KURNAKOW, S. ZEMCZUZNY, and M. ZASEDATELEV (Russia).
4. " Some Tin-Aluminium-Copper Alloys." By Professor A. A. READ, D.Met., and R. H. GREAVES, M.Sc. (Cardiff).
5. " Electric Furnaces as applied to Non-Ferrous Metallurgy." By Professor A. STANSFIELD, D.Sc., A.R.S.M. (Canada).
6. " The Annealing of Nickel-Silver. Part I." By F. C. THOMPSON, M.Met., B.Sc. (Sheffield).
7. " Notes on the Analysis of Aluminium and its Alloys." By W. H. WITHEY, B.A. (Teddington).

The special feature of the next General Meeting of the year was the May Lecture, which was delivered in the evening of May 4, 1916, by Professor W. H. Bragg, D.Sc., F.R.S. (Nobel Prizeman), on " X-Rays and Crystal Structure, with Special Reference to Certain Metals." Professor H. C. H. Carpenter, M.A., Ph.D., Vice-President, occupied the chair, in the absence, through illness, of the President. A full report of the Lecture will be found in the current Journal.

The third General Meeting of the Institute was held in London in the rooms of the Chemical Society on September 20, 1916. The President was in the chair. The following papers were read and discussed at that Meeting :

1. " The Allotropy of Silver." By Dr. W. D. HELDERMAN (Holland).
2. Note on " Cadmium in Spelter." By W. R. INGALLS (U.S.A.).
3. " The Annealing of Arsenical Brass containing 61 and 62·5 per Cent. of Copper. A Study of the Structure and Properties developed by Varying the Rate of Cooling within the Transformation Range." By C. H. MATHEWSON and E. M. THALHEIMER (U.S.A.).
4. " The Development of the Spelter Industry." By ERNEST A. SMITH, A.R.S.M. (Sheffield).

The thanks of the Council are offered, respectively, to the Councils of the Chemical Society and the Institution of Electrical Engineers for allowing the Institute to use their buildings and rooms on the occasions of the above-mentioned Meetings.

Change of Offices.

In January 1916 the Council appointed a sub-committee to inquire and report as to the possibility of securing " more commodious and quieter premises on the expiry of the current lease." Inquiries extending over several months showed that so great was the Government demand for office accommodation that very little that was suitable was available. The Council therefore decided to take no further steps until after the war, when it was expected that there would be much good accommodation available at reasonable rents. In December, however, the Government began to take over certain offices in Caxton House. As there was a prospect that the Institute's offices might be commandeered the sub-committee made further inquiries and selected a suite of rooms at 36 Victoria Street, on which an option was given pending the receipt of notice from the War Office to leave Caxton House.

In the autumn of 1916 a conference was held of the Presidents and Secretaries of the Iron and Steel Institute, the Institution of Mining and Metallurgy, the Institution of Mining Engineers, and of this Institute, with a view to discussing the possibility of the setting up of a joint building for the four societies. The proposal, which was approved in principle by the Council, is now receiving detailed consideration, and the various institutions are arranging not to renew their existing leases beyond a short period, so as to be free to move if and when the scheme can be carried into effect.

Committee Meetings.

The Council has held monthly meetings through the year, and the standing Committees, known respectively as the Corrosion Committee, the Library and Museum Committee, the Finance and General Purposes Committee, and the Publication Committee, have met regularly, and several occasional committees have been appointed by the Council for the consideration of special matters. A new Committee on Increase of Membership has been appointed.

Corrosion Research Committee.

The reconstitution of the old Corrosion Committee, which was decided upon by the Council in 1916, has been effected during the past year. The members of the Committee are now appointed as to one-half by the Council and as to the other half by certain Government

Departments, public bodies, societies, and institutions interested in the subject of the corrosion of the non-ferrous metals. Professor Carpenter has been appointed Chairman of the Committee. Following the reconstitution of the Committee there was received in March from the Government, through the Department of Scientific and Industrial Research, a grant of £325 towards the expenses of the Committee for the six months ended September 30, 1916. The grant was conditional upon the appointment of a salaried investigator, who would devote his whole time to carrying on the corrosion research investigations at the Committee's Research Station in the University of Liverpool. The Committee were successful in securing the services of Dr. G. D. Bengough, M.A., as investigator, notwithstanding the fact that he holds a captaincy in the Army. As assistant investigator the Committee appointed Dr. O. F. Hudson, of the University of Birmingham. On indication being given to the Committee that the Department of Scientific and Industrial Research would be prepared to increase their grant to the sum of £900 per annum as from October 1, 1916, it was decided, on the invitation of Professor Carpenter, to transfer their laboratory to the Metallurgical Department of the Royal School of Mines. Thanks to the kind interest of one of their members, Mr. J. Christie, they were enabled also to establish an experimental sea-water corrosion station in the Corporation Electricity Works at Brighton. As a result, condenser tubes can now be tested under actual working conditions at Brighton. The setting up of these laboratories has necessarily involved the Committee in considerable financial outlay which will not be met by the Government grant, and towards which donations—one of £100 has already been made—will be welcome. As regards the experimental work carried out during the year, this has necessarily been much hampered by the difficulties and delays in obtaining equipment and apparatus, and the new laboratory at the Royal School of Mines was in consequence not completed and ready for occupation until three months later than had been anticipated. By the kindness of Professor Carpenter temporary quarters were provided for the Committee's investigators, and work was commenced early in November on a comprehensive scheme which had been approved by the Committee. This scheme includes a detailed study of a number of factors which have been suggested as determining the initiation of corrosion, and an attempt to estimate their relative importance in the case of a pure metal. A start has been made on the study of certain physical factors, and on the influence of small quan-

tities of " impurities," such as oxide. It is believed that the knowledge so obtained will help materially in the interpretation of results already obtained in the investigation of brass and other alloys.

As regards work on condenser tubes, the whole of those tested at Liverpool have been withdrawn from the condenser and examined. A number of interesting data have been obtained which, as indicated above, cannot be fully interpreted in the light of existing knowledge of fundamental factors. Nevertheless, since long periods of time are required for practical tests in condensers, it has been decided to proceed with these tests simultaneously with the purely scientific work, and arrangements are being made at Brighton to test simultaneously eight sets of tubes instead of four, which was all that was possible in the Committee's original plant. In addition, four sets of tubes will be placed in the main condensers of the Brighton Corporation's Power Station, in which the Cumberland electrolytic protection system is installed. All this part of the work has been much delayed by the difficulty of obtaining from the various makers the necessary sets of tubes, such delays being due, presumably, to pressure of Admiralty and War Office orders.

The Committee desire to express their appreciation of the facilities afforded them by the authorities of the University of Liverpool during the several years that the work was carried on in that University.

Birmingham Local Section.

The membership of the Section for the Sixth Session was as follows :

Members	.	.	.	.	.	.	53
Associates	.	.	.	.	.	.	26
		Total	.	.	.	.	79

The total membership at the end of last session was 85.

The Committee did not consider it advisable to arrange a large programme for the past session ; it was therefore restricted to two Meetings :

1915.
Nov. 23. Chairman's Address. By Mr. C. H. Barwell.
1916.
Feb. 15. Discussion on " The Future of Metallurgical Industries."

Dr. Hudson's removal from the district is a distinct loss to the Local Section, he having acted as Honorary Secretary during the last two sessions.

JOURNAL.

Two volumes of the Journal were published in 1916, Volume XV. and Volume XVI., the publication of the latter being somewhat delayed owing to printer's difficulties. Notwithstanding the war, the number of Papers and Abstracts has been maintained; also the sale of the Journal. No fewer than 420 copies of the Journal were sold during the past financial year, bringing in a revenue of £320 2s. 10d., as compared with £181 19s. 5d. in the previous year.

HONOURS AND APPOINTMENTS.

The Council are especially pleased to record the conferment of the honour of knighthood upon the President of the Institute, Sir George Beilby, LL.D., F.R.S.

In response to the invitation of the Department of Scientific and Industrial Research, Sir Gerard Muntz, Bart., and Professor A. K. Huntington, A.R.S.M., were appointed to represent the Council upon the Metallurgical Committee; Professor Carpenter and Dr. Desch have also been appointed members. Sir Gerard Muntz has since been elected Chairman of this Committee and of the Non-Ferrous Metallurgy sub-Committee; he is also Chairman of the Non-Ferrous Trades Post Bellum Reconstruction Committee, as well as a member of the Committee on Commercial and Industrial Policy. Professor Huntington was appointed a member of the Advisory Panel of the Munitions Inventions Department, on which five members of the Institute are now serving.

Signed on behalf of the Council,

GEORGE BEILBY, *President.*

H. C. H. CARPENTER, *Vice-President.*

March 14, 1917.

The PRESIDENT, in moving the adoption of the Report, said it must be gratifying to all the members, as it was to the Council, that, in spite of the terrible war conditions under which the people of the country were at present living, the Institute had gone on and prospered, partly no doubt because the work of the able men who constituted its membership had been so

much in request for Munition work, and for the metallurgical work that was associated with the Army and the Navy. There had been an extraordinary amount of mental activity on the subject of the metallurgy of the non-ferrous metals, not only in this country, but all over the world. That had reacted on the Institution in a useful manner, and it therefore had had an exceptionally good year in the matter of membership, finance, and the papers that had been presented. As would be observed from the first page of the Report, the membership had reached the highest total on record, namely, 660, and when the result of the ballot for the election of new members was announced at a later stage, it would be found that a further substantial addition had been made to the membership. On the second page of the Report the Council referred with satisfaction to the fact that Professor Sir William Crookes and Sir J. J. Thomson had been elected Honorary Members of the Institute. Those two gentlemen had done the Institute a great honour in accepting the honorary membership —an honour which all the members, he was sure, appreciated most highly. Dealing with the least agreeable side of the Institute's affairs, the Council recorded with sincere regret the death of a number of members, among whom Captain W. Morton Johnson and Engineer-Commander R. Main had been killed in action. The new and very satisfactory start which had been made in connection with the work of the Corrosion Committee was referred to very fully in the Report. He proposed " That the Report of the Council be adopted."

Dr. Richard Seligman formally seconded the motion, which was carried unanimously.

The President announced that the Honorary Treasurer, Mr. A. E. Seaton, was unavoidably prevented from attending the Meeting, and in his absence he would ask Professor Turner to present Mr. Seaton's Report and Account of Receipts and Payments.

Professor Thomas Turner (Vice-President) then read the following Report and Account of Receipts and Payments :

TREASURER'S ACCOUNT OF RECEIPTS AND PAYMENTS FOR YEAR ENDING JUNE 30, 1916.

RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance from last Account—						
Lloyd's Bank Limited—						
Deposit Account	£764	6	3			
General	170	1	3			
Cash in hand of Secretary	16	12	7			
,, ,, Treasurer	5	6	0			
				£955	6	1
,, Subscriptions (including Entrance Fees)	£1370	15	9			
,, Sales of Journal	320	2	10			
,, Miscellaneous Receipts	2	9	6			
,, Donations	6	6	0			
,, Sale of War Loan Rights	2	0	0			
,, Interest on War Loan	43	4	0			
,, ,, ,, Deposit Account	7	7	10			
				1752	5	11
				£2707	12	0

PAYMENTS.

	£	s.	d.	£	s.	d.
By Expenses of Meeting				£42	19	5
,, ,, Journal				602	13	9
,, MANAGEMENT EXPENSES—						
Salaries	£527	4	2			
Rent, Rates, Insurance, &c.	181	9	0			
Printing and Stationery	49	3	5			
Postages, Travelling Expenses, and Sundries	79	10	9			
				837	7	4
,, May Lecturer's Honorarium				10	10	0
,, Purchase of £1200 £4 10s. 0d. per Cent. War Stock				1186	0	5
,, Balance forward—						
Cash in hand of Secretary	£24	2	7			
,, ,, Treasurer	4	6	0			
				28	8	7
Less Lloyd's Bank Limited, overdrawn				0	7	6
				28	1	1
				£2707	12	0

INVESTMENT ACCOUNT.

	£	s.	d.		£	s.	d.
To Investment	£1186	0	5	By £1200 £4 10s. 0d. per Cent. War Stock at cost	£1186	0	5

I hereby certify that I have audited the Accounts of the Institute of Metals for the year ending June 30, 1916, and in my opinion the above Account is a correct statement of the Receipts and Payments for that period.

(Signed) G. GRAHAM POPPLETON, Chartered Accountant,

BIRMINGHAM, LONDON, AND SHEFFIELD.

(Honorary Auditor.)

December 1, 1916.

REPORT OF THE HONORARY TREASURER.

(Mr. A. E. SEATON, M.Inst.C.E.)

In presenting the Balance Sheet for the year ended June 30, 1916, I would call attention to the fact that our financial position had then improved to the extent of over £200. We commenced our year with £955 6s. 1d. at our Bankers, and at its close we possessed £1186 in War Loan Stock and a balance at Bank of £28 1s. 1d.

This is to no small extent due to the extraordinary sales of the Journal, aggregating as they have done to £320. I am pleased to say that the sales still keep good, and although they may not amount to so much in the current year, they will be substantial.

The subscriptions, including Entrance Fees, have reached £1370 15s. 9d. as against £1335 in the preceding year. We estimate that in the current financial year they will amount to about £1350.

It behoves us all to do our utmost to increase the membership of the Institute ; by a " combing in " process exercised by all our members considerable additions may still be made.

I have to report that we had to our credit at the Bank at the end of December 1916 the sum of £858 19s. 9d.

I am also pleased to state that the old Corrosion Committee had in hand at the Bank at the end of December the sum of £376 2s. 6d., and the new Corrosion Research Committee a balance of £865 7s. 0d.

Professor Turner, in moving the adoption of the Report and of the Accounts, said that, as the President had already indicated, the Institute had had a very successful year not only in connection with its papers and membership, but also in relation to finance. It would be seen by reference to the Report of the Honorary Treasurer, whose absence the members very much regretted, that the Institute commenced the year with, in round figures, £955 in the Bank, and that it finished the year with £1186 in War Loan Stock and a balance in hand of £28. That meant that the Institute had improved its financial position to the extent of over £200 during the year. It was impossible to avoid pointing out, in dealing with the finances of the Institute, the important source of income it possessed in the sale of the

Journal. The Institute was exceptional in the respect that there was a great demand for the Journal by those who did not enjoy the privilege of membership, and by libraries and other public bodies. The subscriptions, even in the past year of unprecedented stress, had been somewhat greater than they were in the previous year ; and taking into consideration the condition of the accounts as a whole, he thought it might be said that the Institute had done very well indeed. It had met all its responsibilities ; it had added to the reserve ; and it had also been able to help the country by taking up what was, for the Institute, a considerable amount of War Loan. He had very much pleasure in proposing the adoption of the Honorary Treasurer's Report.

Mr. W. E. OAKDEN formally seconded the motion, which was carried unanimously.

The PRESIDENT thought the very satisfactory financial Report was to a very considerable extent due to the careful work and supervision of the Honorary Treasurer, to whom he desired to propose that a hearty vote of thanks be accorded for his work during the past year.

Mr. JOHN DEWRANCE seconded the motion, which was carried unanimously.

ELECTION OF OFFICERS.

The CHAIRMAN then called upon the Secretary to announce the result of the ballot for the election of officers to replace the retiring President, two Vice-Presidents, and five Members of Council, the list as read being as follows :

President.

Sir GEORGE BEILBY, F.R.S., LL.D., Glasgow.

Vice-Presidents.

L. SUMNER, M.Sc.	Manchester.
Professor T. TURNER, M.Sc., A.R.S.M. . . .	Birmingham.

Members of Council.

W. H. Allen	Bedford.
A. Cleghorn	Glasgow.
J. Dewrance.	London.
S. Evered	Birmingham.
A. Philip, B.Sc., A.R.S.M.	Portsmouth.

Dr. A. G. C. Gwyer, in proposing a hearty vote of thanks to the President and the Council for their work during the past year, said that in view of the magnificent work that had been done as set out in the Report, the members must feel deeply grateful to the Council for their arduous labours. In particular the increase in membership was most satisfactory, and the last voting list that had been sent out was a most formidable one, but fortunately in a healthy direction. He also thought the Council were to be congratulated upon the way in which the work of the Corrosion Research Committee had prospered during the past year, and on the support which had been obtained for it from the Government.

The resolution was carried by acclamation.

The President, in acknowledging on behalf of the Council the vote of thanks which had just been passed, said he flattered himself he could do so in an impartial manner, because the main part of his association with the Institute during the past year had consisted in leaving the Council to do its very excellent work in peace. He had felt the fullest confidence in doing so, and the excellent Report that had been presented at the meeting had justified that confidence. On behalf of his colleagues on the Council, he thanked the members very heartily for the vote of thanks that had been so cordially passed.

Election of Members.

The Secretary read the following list of 102 new members elected as a result of the ballots taken in December 1916 and March 1917 respectively :

Name.	Address.	Qualifications.	Proposers.
Ammon, Mark	355 Batavia Street, Toledo, Ohio, U.S.A.	Metallurgical Engineer, Willys-Overland Automobile Company	A. K. Huntington. Sir G. Beilby. S. L. Hoyt.
Bagnall, Wilfred, B.Met.	151 Upperthorpe, Sheffield	Metallurgist	G. B. Brook. W. R. Barclay. R. S. Hutton.
Barnsley, Frank Herbert	Froome House, Terry Street, Dudley	Engineer, Allen Evered & Sons, Ltd., Smethwick	A. Spittle. S. Evered. J. W. Earle.
Barwell, Cecil Edward	40 Great Hampton Street, Birmingham	Brassfounder	S. Evered. H. L. Reason. A. Spittle.
Bateman, John Hampden	230 Firth Park Road, Sheffield	Chemist and Metallurgist	G. B. Brook. W. R. Barclay. E. A. Smith.
Baxter, Charles	31 Wallingford Avenue, N. Kensington, W. 10	Engineer	H. C. H. Carpenter. T. Turner. Sir G. Beilby.
Beer, Guido, D.Eng., Lieut. of Artillery	Via Montecuccoli, 3, Turin, Italy	Technical Director of Italian Special Bronze Company	M. N. Salvati. L. Archbutt. R. S. Hutton.
Blackhurst, Ira Cartwright	113 Crookes Road, Sheffield	Metallurgist	W. Cleland. G. B. Brook. W. R. Barclay.
Bridgens, Arthur	57 Meersbrook Road, Sheffield	Brassfounder	G. B. Brook. R. S. Hutton. W. R. Barclay.
Cohen, Ernst, Ph.D.	van't Hoff Lab., The University, Utrecht, Holland	Professor of Physical Chemistry	Sir R. A. Hadfield. T. Turner. H. C. H. Carpenter.
Cook, William Garside	Braeside, Woofinden Avenue, Ranmoor, Sheffield	Nickel Refiner	G. B. Brook. W. R. Barclay. R. S. Hutton.
Cooper, Arthur	" One Ash " Dore, nr. Sheffield	Electroplate Manufacturer	R. S. Hutton. G. B. Brook. W. R. Barclay.
Cooper, William James	E. W. Oakes & Co., Ltd., 270 Rockingham Street, Sheffield	Bullion Dealer	G. B. Brook. W. R. Barclay. J. Crowther.
Crosby, William Edward	5 Perth Road, Finsbury Park, N. 4.	Draughtsman and Engineer, Aluminium Plant & Vessel Co.	R. Seligman. A. L. Davis. R. W. Norman.
Crowther, Alan (*Student*)	5 Sharrow Mount, Psalter Lane, Sheffield	Metallurgical Student (on active service)	G. B. Brook. W. R. Barclay. R. S. Hutton.
Cullen, William Geoffrey (*Student*)	53 Osborne Road, Newcastle-on-Tyne	Draughtsman	H. C. H. Carpenter. Sir G. Beilby. W. H. Cullen.

NAME.	ADDRESS.	QUALIFICATIONS.	PROPOSERS.
Davies, Harry	7 Cambridge Crescent, Edgbaston, Birmingham	Metallurgist	T. Turner. O. F. Hudson. F. Johnson.
Davies, Llewellyn John	103 Bute Road, Cardiff	Analytical and Consulting Chemist	A. A. Read. H. S. Thomas. J. Dewrance.
Dean, Stephen Woodhouse	Delta House, Tunnel Avenue, E. Greenwich	Assistant Works Manager	G. B. Brook. W. R. Barclay. E. A. Smith.
Deeley, Samuel Edward	9 Meadow Street, Sheffield	Manager, William Rowland, Ltd.	G. B. Brook. W. R. Barclay. R. S. Hutton.
Derbyshire, Sydney Frank	Curbar House, Newbold Moor, Chesterfield	Lecturer Non-ferrous Met. Dept., University of Sheffield	G. B. Brook. R. S. Hutton. W. R. Barclay.
Doyle, Arthur Lawton, B.Sc.	9 Greenwood Lane, Woodhouse, Sheffield	Analytical Chemist	G. B. Brook. R. S. Hutton. W. R. Barclay.
Dunstan, Albert Edward	The Beeches, Woodhouse, nr. Sheffield	Director, Kent Smith, Limited	G. B. Brook. W. R. Barclay. R. S. Hutton.
Durran, Richard Thomas	35 St. James's Place, W. 1	Engineer	H. C. H. Carpenter. J. H. R. Kemnal. A. Spyer.
Earle, Kenneth Luton	Earle, Bourne & Co., Ltd., Lejona, Bilbao, Spain	Metal Manufacturer	E. E. Dendy. C. Y. R. Bedford. J. H. Allen.
Elam, Constance Fligg	Addington House, New Barnet, Herts	Experience at N.P.L., Natural Science Tripos, Cambridge	H. C. H. Carpenter. B. W. Drinkwater. L. Taverner.
Elton, Leo	11–13 Creechurch Lane, E.C. 3	Interested in utilization of residues and waste products of non-ferrous metals	G. Bill-Gozzard. C. A. Russell. E. C. Trubridge.
Etchelles, Harry, B.Met.	231 Oakbrook Road, Sheffield	Metallurgical Engineer	G. B. Brook. W. R. Barclay. R. S. Hutton.
Evans, Alfred John, M.A., B.Sc.	266 Lower Addiscombe Road, Croydon	Metallurgist	H. H. A. Greer. J. Stevens. A. Cleghorn.
Fletcher, Joseph Ernest	Raydon, Himley Road, Dudley	Engineer and Metallurgist	H. C. H. Carpenter. T. Turner. O. F. Hudson.
Forest, Alfred V. de	Stratford, Conn., U.S.A.	Research Engineer	A. E. Seaton. Sir C. A. Parsons. S. L. Hoyt.
Foulston, Herbert	239 Abbeyfield Road, Sheffield	Manager, Manufacturing Co., extensively using lead, tin, and antimony	G. B. Brook. W. R. Barclay. R. S. Hutton.

Name	Address.	Qualifications.	Proposers.
Francillon, Jean Baptiste	Le Bourget (Seine), France	Directeur de la Société l'Etirage	A. E. Seaton. J. Dewrance. J. T. Milton.
Fritch, Giles Morton, B.Sc.	American Brass Co., Kenosha, Wis., U.S.A.	Metallurgist and Chemist	W. H. Bassett. D. R. Hull. H. C. Jennison.
Fry, John	25–30 Holland Street, Blackfriars, S.E. 1	Metal Refiner, Manufacturer Shrapnel Bullet Metal, Printing Metals, &c.	L. H. Quin. P. W. Smith. E. G. King.
Fuller, Truman S., B.Sc.	Research Laboratory, General Electric Co., Schenectady, N.Y., U.S.A.	Metallurgist	A. K. Huntington W. R. Whitney. S. L. Hoyt.
Garratt, Walter Reginald, M.Sc.	128 Blair Athol Road, Ecclesall, Sheffield	Metallurgist	R. S. Hutton. G. B. Brook. W. R. Barclay.
Gibbs, William Edward, M.Sc.	Government Rolling Mills, Southampton	Chief Chemist	Edwin Grice. G. D. Bengough. H. C. H. Carpenter.
Giles, Frederick John	Heath Street, South, Birmingham	Metal Manufacturer, Director & General Man. Metal Coy.	E. E. Dendy. C. Y. R. Bedford. J. H. Allen.
Gillies, Capt. William Douglas	23 Brocco Bank, Sheffield	Director of Silver-refining Company	G. B. Brook. R. S. Hutton. W. R Barclay.
Greenwood, John Neill, B.Sc. (*Student*)	Research Dept., Sir G. Armstrong, Whitworth & Co., Manchester	Metallurgist	E. F. Law. C. A. Edwards. J. H. Andrew.
Gummer, George	Park Mount, Clifton Lane, Rotherham	Brassfounder	G. B. Brook. W. R. Barclay. R. S. Hutton.
Hall, Isaiah H.	Manor Hall, Harborne, Birmingham	Inventor and Patentee of Monometer Metal-melting Furnaces	G. B. Brook. W. R. Barclay. R. S. Hutton.
Hampton, Harold John	Admiralty Laboratory, Workington, Cumberland	Analytical Chemist	G. B. Brook. W. R. Barclay. R. S. Hutton.
Hanson, Daniel, M.Sc.	National Physical Laboratory, Teddington, Middlesex	Metallurgist	W. Rosenhain. J. L. Haughton. Sir G. Beilby.
Harvey, Leonard Charles	Battersea Works, London, S.W.	Furnace Engineer and Designer, Morgan Crucible Co., Ltd.	Sir T. K. Rose. Sewell H. Gregory. C. O. Bannister.

Name.	Address.	Qualifications.	Proposers.
Hobson, Albert John	Esholt, Ranmoor, Sheffield	Cutlery and Electroplate Manufacturer, Pro-Chancellor, Sheffield University	G. B. Brook. W. R. Barclay. R. S. Hutton.
Hodgson, George Hugh	Admiralty Laboratory, Midland Institute, Birmingham	Metallurgical Chemist	G. B. Brook. W. R. Barclay. R. S. Hutton.
Hurst, Cecil Henry	33 Moor Oakes Road, Sheffield	Metallurgist	G. B. Brook. W. R. Barclay. R. S. Hutton.
Ibbotson, Robert	Ashdell Lodge, Ashdell Road, Sheffield	Demonstrator in Metallurgy	G. B. Brook. W. R. Barclay. James Crowther.
Jackson, Francis Munton	117 Colmore Row, Birmingham	Electrical and Civil Engineer	G. B. Brook. W. R. Barclay. R. S. Hutton.
Jeffries, Zay, B.Sc., Met.E.	Case School of Applied Science, Cleveland, Ohio, U.S.A.	Metallurgist, Assistant Professor of Metallurgy, Case School of Applied Science	H. M. Howe. Sir George Beilby. S. L. Hoyt.
Kay, Frank	Bolton Brass Works, Blackhorse Street, Bolton	Brass and Bronze Founder, Manufacturer and Alloyer of Non-ferrous Metals	L. Sumner. C. A. Edwards. W. E. Thornycroft.
Kermode, Georgina Elizabeth	45 Carlisle Mansions, S.W. 1	Director of Metals Extraction Companies	T. Turner. Sir G. Beilby. A. K. Huntington.
Lloyd, Trevor Wyndham (*Student*)	293 Dykes Lane, Wadsley, Sheffield	Analytical Chemist	G. B. Brook. R. S. Hutton. W. R. Barclay.
McCance, Andrew, A.R.S.M.	63 Lauderdale Gardens, Hyndland, Glasgow	Metallurgist	H. C. H. Carpenter. B. W. Drinkwater. L. Taverner.
Marsland, Stanley (*Student*)	809 Attercliffe Road, Sheffield	Student in Metallurgy	G. B. Brook. W. R. Barclay. R. S. Hutton.
Mathewson, Champion Herbert, Ph.D.	Hammond Laboratory, Sheffield Scientific School, New Haven, Conn., U.S.A.	Assistant Professor of Metallurgy, Sheffield Scientific School	H. M. Howe. H. Fay. S. L. Hoyt.
May, Walter Frederick Nunn	May & Podmore, Ltd., Leopold Street, Birmingham	Brassfounder	S. Evered. A. Spittle. J. W. Earle.
Morton, James Albany	73 Robertson Street, Glasgow	Metallurgist	H. C. H. Carpenter. B. W. Drinkwater. L. Taverner.

Name.	Address.	Qualifications.	Proposers.
Morton, James Alfred	125 Northfield Road, Sheffield	Spoon and Fork Works Manager	G. B. Brook. R. S. Hutton. W. R. Barclay.
Oakes, Edmund William	56 Nether Edge Road, Sheffield	Assistant Analyst	G. B. Brook. R. S. Hutton. W. R. Barclay.
Paine, Stanley William Thomas (*Student*)	48 Southfields Road, Wandsworth, S.W. 18	Apprentice Draughtsman and Engineer, Aluminium Plant and Vessel Co.	R. Seligman. A. L. Davis. P. W. Norman.
Perfect, F. W. (*Student*)	69 Horsedge Street, Oldham	Chemical Student	A. Carter. A. K. Huntington. A. E. Seaton.
Pollock, Arthur Leagus	12 Westfield Road, Surbiton	Draughtsman and Engineer, Aluminium Plant and Vessel Co.	R. Seligman. A. L. Davis. P. W. Norman.
Pugsley, Thomas Montague	17 Osgathorpe Road, Sheffield	Works Chemist	G. B. Brook. W. R. Barclay. R. S. Hutton.
Pulsifer, Harrie Bridgman	Armour Institute of Technology, Chicago, Ill., U.S.A.	Metallurgist, Asst. Professor of Metallurgy	H. Fay. H. M. Boylston. R. S. Williams.
Redding, Richard James, Wh.Sc.	Government Rolling Mills, Southampton	Asst. Supt. Metallurgical Govt. Rolling Mills	Edwin Grice. R. S. Hutton. W. R. Barclay.
Redmayne, Laurence	52 Baunerdale Road, Sheffield	General Founder	G. B. Brook. R. S. Hutton. W. R. Barclay
Ruddock, Frederick Amory	70 Admiralty Laboratory, Midland Institute, Birmingham	Metallurgical Chemist	G. B. Brook. W. R. Barclay. R. S. Hutton.
Ruder, William Ernest, B.S.	642 Rugby Road, Schenectady, N.Y., U.S.A.	Metallurgist	Sir G. Beilby. W. R. Whitney S. L. Hoyt.
Ryder, Henry Martyn	Mappin & Webb, Ltd., Royal Works, Sheffield	General Manager, Mappin & Webb, Ltd.	G. B. Brook. W. R. Barclay. R. S. Hutton.
Salvati, Michele Natale	Via Montecuccoli 3, Turin, Italy	Metallurgical Engineer, Chairman Italian Special Bronze Co.	H. C. H. Carpenter. T. Turner. W. Rosenhain.
Sissons, Harold Gordon (*Student*)	230 Graham Road, Sheffield	Student in Metallurgy	G. B. Brook. W. R. Barclay. R. S. Hutton.
Sissons, Walter	230 Graham Road, Sheffield	Silver Plate Manufacturer	G. B. Brook. W. R. Barclay. R. S. Hutton.

NAME.	ADDRESS.	QUALIFICATIONS.	PROPOSERS.
Smith, Cyril Coldron, B.Sc., A.R.S.M. (*Student*)	Royal School of Mines, South Kensington, S.W. 7	Research Student in Metallurgy	H. C. H. Carpenter B. W. Drinkwater. L. Taverner.
Smith, Joseph Kent	59 Clarkgrove Road, Sheffield	Metallurgist	G. B. Brook. W. R. Barclay. R. S. Hutton.
Smout, Arthur John G.	53 Lordswood Road, Harborne, Birmingham	Analytical Chemist and Metallurgist engaged in manufacture of non-ferrous metals and alloys	E. E. Dendy. F. Platten. T. Turner.
Stanley, Ernest	21 Parkview Road, Croydon	Works Manager, Aluminium Plant and Vessel Co., Ltd.	R. Seligman. A. L. Davis. P. W. Norman.
Stanton, Diggory	1 Finsbury Circus, E.C. 2	Mining Engineer	G. B. Brook. W. R. Barclay. R. S. Hutton.
Stewart, Alexander Robertson	Strathclyde, Walton Road, Stockton Heath	Rolling-mill Superintendent	W. Rosenhain. J. L. Haughton. A. G. C. Gwyer.
Stone, George Ernest Murray	" Northfield," Dronfield Woodhouse, Sheffield	Pyrometry Expert	G. B. Brook. W. R. Barclay. R. S. Hutton.
Summers, Percy Francis, A.R.S.M.	14 Mayow Road, Forest Hill, S.E. 23	Metallurgist	H. C. H. Carpenter. B. W. Drinkwater. L. Taverner.
Taylor, James Henry	Hollis Croft, Sheffield	Brass Founder	G. B. Brook. W. R. Barclay. R. S. Hutton.
Thompson, Frank Charles, D.Met., B.Sc.	37 Filey Street, Sheffield	Demonstrator in Metallurgy, Sheffield University	G. B. Brook. W. R. Barclay. R. S. Hutton.
Toller, F. T. Frank	78 Hatton Garden, E.C. 1	In Platinum Dept., Johnson, Matthey & Co. Ltd.	R. M. Walmsley. A. J. Webb. R. M. N. Dawlings.
Tosi, Gianfranco	Legnano, Italy	Engineer	H. C. H. Carpenter. Sir G. Beilby. A. K. Huntington.
Turner, Thomas Henry	78 Hatton Garden, E.C. 1	Manager, Rolling-mills working with precious metals	A. J. Webb. J. Phelps. S. W. Smith.
Upton, Alfred Ernest	43 Rossington Road, Brocco Bank, Sheffield	Departmental Manager, Vickers Ltd., Sheffield	F. Mason. G. B. Brook. W. R. Barclay.
Varney, Theodore	2400 Oliver Bldg., Pittsburgh, Pa., U.S.A.	Electrical Engineer, Aluminium Company of America	A. K. Huntington. Sir C. A. Parsons. S. L. Hoyt.

Name.	Address.	Qualifications.	Proposers.
Ward, Albert	15 Kelvin Grove, Cheetham, Manchester	Consulting Engineer	H. Rix. H. J. Widdowson. C. A. Edwards.
Ward, Thomas William	60 Endcliffe Vale Road, Sheffield	Metal Merchant and Engineer	W. R. Barclay. G. B. Brook. E. A. Smith.
Watkin, George S. (*Student*)	84 Glencoe Road, Sheffield	Student in Metallurgy	G. B. Brook. W. R. Barclay. R. S. Hutton.
Watson, Thomas Henry	The Folds, Beauchieff, Sheffield	Alloy Manufacturer	G. B. Brook. W. R. Barclay. R. S. Hutton.
Whiteman, George Hewit	51 Carpenter Road, Edgbaston, Birmingham	Metal Manufacturer	A. Spittle. S. Evered. J. W. Earle.
Wigley, Frederick Samuel	121 Colmore Row, Birmingham	Architect and Patentee of brass-melting furnace	H. L. Reason. J. H. Wilson. G. A. Boeddicker.
Williams, Percy, B.Sc.	94 Telford Avenue, Streatham Hill, S.W. 2	Chemist, Aluminium Plant and Vessel Co., Ltd.	R. Seligman. P. W. Norman. A. L. Davis.
Wilson, Morton	Millhouse Lane, Sheffield	Works Manager, John Round & Son, Ltd.	G. B. Brook. W. R. Barclay. R. S. Hutton.
Wilson, William A. R.	6 Edgemount Road, Sheffield	Electroplate Manager	G. B. Brook. W. R. Barclay. R. S. Hutton.
Wolseley, Arthur Hugh	Fazeley Street Mills, Birmingham	Manager and Director, Charles Clifford & Son, Ltd.	Sir G. A. Muntz. C. H. Barwell. J. G. Brockbank.
Wragg, John Hobson	36 Wostenholm Road, Sheffield	Metallurgist and Engineering Chemist	R. S. Hutton. G. B. Brook. W. R. Barclay.
Yates, Harry James	Redcroft, Four Oakes, Warwickshire	Engineer	E. E. Dendy. J. W. Earle. G. H. Dugard.

The President said he had very great pleasure in declaring the 102 ladies and gentlemen whose names had just been read out duly elected members of the Institute. The Institute had more than doubled its previous record in electing 102 members, the highest total that had previously been elected being 47. Of the 102 new members, 2 were ladies, 10 students, and 90 ordinary members. The present total membership of the Institute was: Honorary Members, 4; Ordinary Members, 729;

and Student Members, 17.   He felt peculiarly proud and happy that the introduction of women members into the Institute had occurred during his term of office.   As President he desired most cordially to welcome into their midst the women who were now going to work side by side with the present members.   He hoped they would take an important share in the work in new and useful directions, and thereby bring a great stimulus to the whole of the work of the Institute.   He was also requested to announce that a further ballot for the election of new members would be held in connection with the May Lecture on May 3 ; the names of new candidates must be sent in by April 25th.

Election of Auditor.

On the motion of the President, Mr. G. G. Poppleton was unanimously re-elected Auditor of the Institute for the year 1917.

Professor Turner, in moving that a hearty vote of thanks be accorded to Mr. Poppleton for his services as Honorary Auditor, said that he had been brought into contact with Mr. Poppleton in connection with his work for a number of years past, and therefore knew that the Auditor was most careful in the work that he performed.   The Institute possessed in Mr. Poppleton a trustworthy officer who had its interests at heart, and he was sure that the members had done well in reappointing him to his position.   He had much pleasure in moving that the hearty thanks of the members be given to Mr. Poppleton for the gratuitous services he had rendered for a number of years past.

The resolution of thanks was carried by acclamation.

The President said that they had now arrived at the constructive part of the programme.

The following communications were then read in abstract :

1. Paper : " The General Properties of Stampings and Chill Castings in Brass of approximately 60 : 40 Composition." By OWEN WILLIAM ELLIS, B.Sc. (Birmingham).
2. Note : " On Machining Properties of Brass." By OWEN WILLIAM ELLIS, B.Sc. (Birmingham).
3. Paper : " Surface Tension and Cohesion in Metals and Alloys." By SYDNEY W. SMITH, D.Sc., A.R.S.M. (London).
4. Paper : " Annealing of Nickel Silver (Part II.)." By F. C. THOMPSON, D.Met., B.Sc. (Sheffield).

All the above communications were discussed.

5. Note : " Aluminium Production by Electrolysis : A Note on the Mechanism of the Reaction." By R. SELIGMAN, Ph.Nat.D. (London), was taken as read.

In the case of each of the above Papers and Notes a hearty vote of thanks to the authors was proposed by the Chairman and carried with acclamation.

The proceedings were adjourned at 10 P.M. until 4.30 P.M. the following day, Thursday, March 22.

SECOND DAY'S PROCEEDINGS.

Thursday, March 22, 1917.

METAL MELTING DISCUSSION.

At the adjourned meeting, which was again presided over by the President, Sir George Beilby, F.R.S., LL.D., a General Discussion on Metal Melting took place, this being prefaced by the reading of the following communications in abstract :

1. Paper : " Metal Melting as practised at the Royal Mint." By W. J. HOCKING (London).
2. Paper : " Coal Gas as a Fuel for the Melting of Non-Ferrous Alloys." By G. B. BROOK (Sheffield).
3. Paper : " High-Pressure Gas Melting." By C. M. WALTER, B.Sc. (Birmingham).
4. Paper : " Contribution to Metal Melting Discussion." By H. M. THORNTON and H. HARTLEY, M.Sc. (London).

After the above four communications had been presented the President proposed a vote of thanks to the authors, which was carried by acclamation. There then followed a general

discussion of all the papers, the proceedings being adjourned from 6.30 P.M. until 7.45 P.M.

At the evening session the Metal Melting Discussion was continued, and opened by the presentation, in abstract, of the following communications :

1. Note : " Coke-Fired Furnaces." By H. L. Reason (Birmingham).
2. Note : " An Electric Resistance Furnace for Melting in Crucibles." By H. C. Greenwood, D.Sc. (London), and R. S. Hutton, D.Sc. (Sheffield).
3. Paper : " Ideals and Limitations in the Melting of Non-Ferrous Metals." By Carl Hering (Pa., U.S.A.).
4. Note : " Metal Melting in a Simple Crude Oil Furnace." By H. S. Primrose (Ipswich).
5. Note : " A New Producer Gas Fired Crucible Furnace." By T. Teisen, B.Sc. (Birmingham).

After the five above communications had been presented (Nos. 3 and 4 being read in abstract by the Secretary in the absence of the authors) the President proposed, and there was carried by acclamation, a vote of thanks to the authors. There then followed a general discussion of all the communications.

Concluding Business.

The President proposed a vote of thanks to their hosts, the Chemical Society, as follows : " That the best thanks of the Institute be and are hereby tendered to the Council of the Chemical Society for their courtesy in permitting the use of their rooms on the occasion of this meeting."

Sir Gerard Muntz, Bart., Past-President, seconded the vote of thanks to the Society for allowing the Institute to use their very commodious and convenient rooms. He was sure that such interchanges of courtesies among societies were always useful. At present the Institute was receiving benefits, but should they ever be installed in their own house—as he hoped they would be—they would be glad to extend them to others.

The vote was passed by acclamation.

Mr. F. W. Fletcher said that, as a visitor, he felt it his duty to propose a vote of thanks to the Council of the Institute of

Metals for inviting so many visitors to be present. As Chairman of a Technical Education Committee, the idea that non-members would be allowed to attend the lectures had appealed to him very strongly indeed. He was certain that the visitors present had highly appreciated the papers to which they had had the pleasure of listening. If the Institute could see their way to hold meetings in other parts of the country, he was convinced that metal workers would be greatly pleased.

The PRESIDENT wished to acknowledge, not only on behalf of the Council, but on behalf of the members of the Institute, the very kind vote of thanks just proposed. It was a source of great pleasure to the meeting that so many visitors were present, and a source of encouragement, showing, as it did, that there were people still outside the Institute who were interested in their proceedings. He hoped that some of their visitors would seriously consider whether they ought not to become members.

Professor A. K. HUNTINGTON, Past-President, asked the members to express their appreciation of the way in which the President had conducted the meeting. It had been a notable meeting in many ways ; it was the first time the Institute had had such a discussion as had taken place, the results of which had been most encouraging. It had brought out a great deal of useful information from practical men, and that was one of the reasons for the existence of the Institute. The quiet, genial presence of the President, his appreciation of the difficulties of those who had taken part in the discussion, and his manner of conducting the meetings, contributed greatly to the influence which the Institute was likely to exert in the future.

Professor H. C. H. CARPENTER, Vice-President, said that he had great pleasure in seconding the vote. As Professor Huntington had said, the meeting had been a most memorable one. It had been accompanied by the election of a record number of members, a record attendance, and one of the best discussions that the speaker could remember.

The PRESIDENT thanked the members heartily for their vote. It had been a great encouragement to preside at so full a meeting, and one marked by such interesting discussions.

The meeting then terminated at 10 P.M.

THE GENERAL PROPERTIES OF STAMPINGS AND CHILL CASTINGS IN BRASS OF APPROXIMATELY 60:40 COMPOSITION.*

By OWEN WM. ELLIS, B.Sc. (BIRMINGHAM).

THE following research has been undertaken in order to ascertain, if possible, the causes of the variations in the machining properties of brass stampings of approximately 60 : 40 composition, and to ascertain means whereby the variations may be lessened.

The research has developed in two directions. In the first place endeavours were made to relate the Brinell hardness numbers of a series of stampings with as many of the factors as were likely to produce variations in the machining properties of the same. Preliminary investigations into the relation between the Brinell hardness numbers and the copper content had shown that this relation could be expressed by means of a linear equation where the copper percentage varied only from 55 to 70. Further, it appeared likely that a similar law could be found connecting the machining times and the copper content of these alloys. Subsequent more extended investigations on a series of specially prepared chill castings and on certain stampings served to show that no such simple and proportional connection did exist between these two factors.

These more extended investigations formed the second line of development, and consisted essentially of an attempt to co-ordinate certain of the physical and mechanical properties of the alloys in question with their chemical composition.

The first line of investigation consisted, as has already been noted, in an endeavour to show that a simple relation, similar to that between the Brinell hardness numbers and the composi-tions of the brasses containing between 55 to 70 per cent. of copper, existed between the latter factor and, in particular, the mechanical and machining properties of the same.

Consideration was made of the possible effect on the Brinell hardness numbers of the finished stampings of varying certain factors in the course of manufacture, keeping in view meanwhile the whole process of manufacture, in order that useless avenues of inquiry might not be opened. These factors are enumerated here and are discussed below.

(*a*) Composition.

(*b*) Casting temperatures and conditions.

(*c*) Stamping temperatures and conditions.

(*d*) Treatment temperatures and conditions.

Assuming, as was erroneously done initially, that the mechanical and machining properties of the finished stampings are simply related to their compositions, a further factor presents itself for examination—

(*e*) Mechanical and physical condition of the machining tool.

(*a*) *Hardness Numbers of Finished Stampings, &c.*

In Fig. 1 are enumerated the Brinell hardness numbers of 52 stampings and 12 heat-treated castings varying in composition
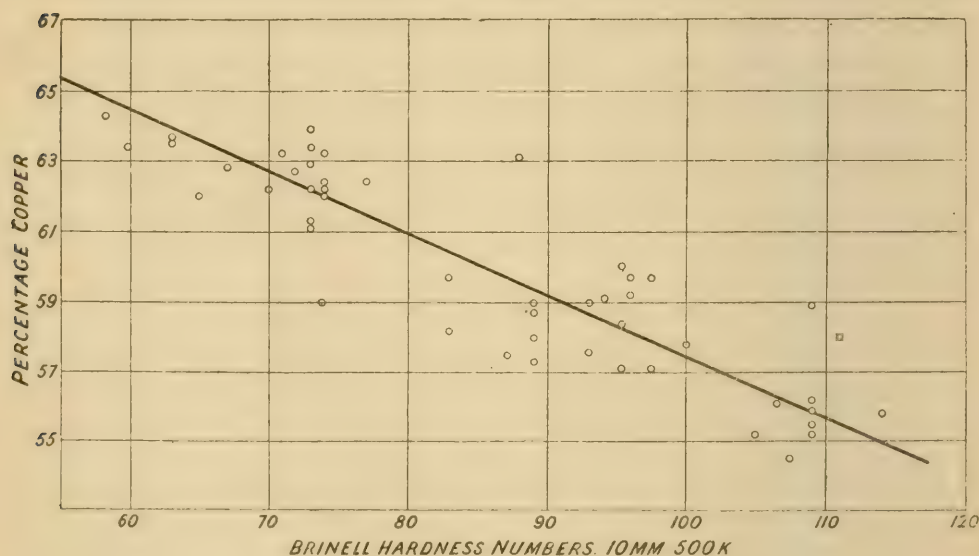

Fig. 1.

from 55·20 per cent. to 66·66 per cent. of copper. The variation in the percentage of lead in these alloys was from 0·45 to 1·34, and the percentage of iron in the same averaged about 0·20.

The relation in question has been hitherto investigated by Professor T. Turner and Professor D. Meneghini. These observers have, however, surveyed the entire field of the copper-zinc alloys. Both agree in representing the relation under consideration by what is practically a straight line in that portion of their hardness composition graphs dealt with here. Their findings are confirmed by the results recorded in Fig. 1, where it is made evident that the ball hardness is inversely proportional to the percentage of copper in those alloys that lie within the limits of 55 per cent. to 60 per cent. copper.

(b) *The Influence of Variations in Casting Temperature and Condition on the Brinell Hardness Numbers and Machining Properties of Stampings.*

Generally speaking, the casting temperature is of little importance in this connection, as the variations in the Brinell hardness numbers of a given series of castings of the same composition are reduced to practically a uniform figure by annealing. As all castings are heated prior to stamping, it is probable that such variations as are due to casting temperature will be eliminated. That annealing does tend to reduce the Brinell hardness numbers of castings of uniform composition to uniform values is shown in Table A, which indicates the effect of annealing six castings

TABLE A.—*The Influence of Variations in Casting Temperature and Condition on the Brinell Hardness Numbers and Machining Properties of Stampings.*

Effect of annealing stamping castings for one hour at varying temperatures.

No.	As Cast.	Annealed. 650° C.	Annealed. 700° C.	Annealed. 750° C.	Annealed. 800° C.
U	77·6	67·6	67·6	65·0	70·0
V	77·6	61·8	64·2	63·4	64·6
W	89·8	81·8	78·8	86·0	86·0
X	94·2	73·6	72·4	68·2	77·0
Y	101·0	82·4	80·6	87·2	85·4
Z	102·0	84·2	84·4	86·0	85·4

at temperatures varying from 650° C. to 800° C. for one hour. If the six samples be considered in pairs—U and V, W and X, Y and Z—the uniformity in the reduction of the Brinell hardness

numbers by annealing is exemplified. Naturally, deficient or excessive casting temperatures are productive of abnormal results, but in average practice the above statements hold good.

By condition of casting is meant the condition of the mould and the manner of pouring the alloy. If the moulds are badly prepared or if the metal is carelessly poured no amount of annealing can eliminate the resultant defects.

(c) *The Influence of Variations in Stamping Temperatures on the Brinell Hardness Numbers and Machining Properties of Stampings.*

The temperature of the casting at the time of stamping and the temperature of the tup, die, and parts adjacent thereto appear to be, after composition, the most important factors in the production of variations in the hardness of the stampings.

Considering the above factors in order—of the first, the temperature of the casting at the time of stamping, it can be said that the higher the temperature (a) the greater the proportion of the hard β constituent in the alloy and (b) the more plastic the mixed α and β constituents. For the benefit of the process it is evident that within certain limits a high temperature should be aimed at, because the alloy will be more plastic ; whereas for the benefit of the product, a low stamping temperature will be more desirable, because a less quantity of the hard β constituent will thus be retained in the finished stamping. But if consideration be taken of the fact that the stamping can and should be subjected to heat treatment subsequent to forging, then the temperature of the stamping will only be governed by a consideration of the benefits likely to be conferred on the process.

Of the second factor, the temperature of the tup, die, and parts adjacent thereto, it can be said that the higher their temperature, the less the " quenching " effect of the same on the stamping. When the tup, die, and adjacent parts are quite cold, as at the beginning of a series of operations, the stamping will be cooled at a considerably greater rate than when these parts are heated, as at the end of a series of operations. The variations thus produced are likely to be very slight, and when it is considered that a subsequent annealing of the stampings will cer-

tainly modify any such differences, it will be seen that this factor is unworthy of further consideration here.

(d) *The Influence of Variations in the Subsequent Heat Treatment of Stampings on the Brinell Hardness Numbers of Stampings.*

The only reference to the Brinell hardness numbers of heat-treated alloys of this series of which the author is aware is to be found in a paper by Dr. Stead.* There are enumerated values obtained on testing a series of 18 specimens of an alloy containing 60·40 per cent. of copper, each sample of which series had been treated thermally in a different manner. Dr. Stead accorded to these samples a heat treatment extending over 48 hours, whereas the specimens considered in this section were annealed for one hour only. Such discrepancies as do exist between the results given below in Tables B and D and those obtained by Dr. Stead are not surprising. The stampings employed in these tests varied in copper percentage from 59·0 to 61·0.

Three sets of investigations were carried through :

1. Twelve unannealed stampings were chosen from a number passing through the shops in the ordinary course of manufacture. These stampings were considered to be hard to machine. In the first place, the stampings were divided into two batches and were numbered 1, 2, &c., and 1A, 2A, &c., respectively. The former batch was heated (i) to 650° C. for an hour and cooled in the furnace, and (ii) re-heated to 650° C. for five minutes and quenched. The latter batch was heated (i) to 780° C. for five minutes and quenched, and (ii) re-heated to 780° C. for an hour and cooled in the furnace. Hardness tests were made on all the members of both batches, (1) as received, (2) after the first heat treatment, and (3) after the second heat treatment. The results of the test are tabulated in Table B.

2. Thirty-six unannealed stampings were chosen at random from a lot passing through the shops in the ordinary course of manufacture. These stampings were divided into batches of six, each batch being designated by a letter, the members of each batch being numbered 1 to 6 respectively. The hardness

TABLE B.—*The Influence of Variations in Annealing Temperatures on the Brinell Hardness Numbers and Machining Properties of Stampings.*

As Received.	Heated to 650° for 1 hour and cooled in Furnace.	Heated to 650° for a few minutes and quenched.
No. 1 71·2	59·0	62·8
2 78·8	67·0	71·8
3 81·8 Variation	70·0 Variation	83·0 Variation
4 97·6 36·4	73·0 14·0	77·0 20·4
5 103·0	67·0	80·0
6 107·4	71·2	74·0

As Received.	Heated to 780° for a few minutes and quenched.	Heated to 780° for 1 hour and cooled in furnace.
No. 1A 85·4	114·0	80·0
2A 86·7	128·8	77·0
3A 89·0 Variation	127·6 Variation	77·0 Variation
4A 90·6 10·6	*94·8 14·8	*63·8 7·8
5A 95·5	121·0	83·0
6A 96·0	127·6	75·2

TABLE C.—*The Influence of Variations in Annealing Temperatures on the Brinell Hardness Numbers and Machining Properties of Stampings.*

Effect of annealing stampings for one hour at varying temperatures.

Number.	Hardness.		Difference.	Number.	Hardness.		Difference
	Before Annealing.	After Annealing.			Before Annealing.	After Annealing.	
A.1	86·0	81·2	4·8	D.1	75·2	67·0	8·2
A.2	84·8	76·4	8·4	D.2	86·0	81·2	4·8
A.3	86·0	78·8	7·2	D.3	78·2	73·2	5·0
A.4	106·6	94·8	11·8	D.4	73·0	69·4	3·6
A.5	84·8	74·6	10·2	D.5	87·2	83·0	4·2
A.6	81·8	73·8	8·0	D.6	105·8	89·8	16·0
Average Diff.			8·4				6·9
Variation 24·8	21·0				32·8	22·8	
B.1	83·8	77·0	6·6	E.1	80·0	77·0	3·0
B.2	84·8	74·6	10·2	E.2	78·2	73·0	5·2
B.3	83·6	76·4	7·2	E.3	88·4	82·4	6·0
B.4	83·6	76·4	7·2	E.4	89·0	81·8	7·2
B.5	84·2	73·6	10·6	E.5	91·4	84·8	6·6
B.6	86·6	79·4	7·2	E.6	87·8	83·0	4·8
Average Diff.			8·2				5·5
Variation 3·0	5·8				13·2	11·8	
C.1	89·0	81·2	7·8	F.1	86·6	80·6	6·0
C.2	86·0	83·0	3·0	F.2	84·2	76·4	7·8
C.3	89·0	81·2	7·8	F.3	82·4	80·0	2·4
C.4	84·2	78·2	6·0	F.4	86·6	86·6	
C.5	84·8	78·2	6·6	F.5	86·0	84·8	1·2
C.6	84·2	80·6	3·6	F.6	84·2	80·6	3·6
Average Diff.			5·8				3·5
Variation 4·8	4·8				4·2	10·2	

* These values appear to be abnormal and are therefore left out of consideration in estimating the variation in Brinell hardness numbers.

numbers of all the stampings, in the condition in which they were received, were first estimated. Two indentations were measured in each case, an average figure being subsequently calculated. The six batches were then annealed at temperatures varying from 550° C. to 800° C. and, after the stampings had been allowed to cool in air, the hardness numbers were again estimated in manner like to that already stated. The results of these tests are given in Table C.

3. The thirty-six stampings of the last paragraph were later divided into two sets. Lots A to C were re-annealed at 650° C. and subsequently cooled in air, lots D to F were re-annealed at 550° C. and likewise cooled. The hardness numbers of all were then estimated as above, the results of these trials being given in Table D.

TABLE D.—*The Influence of Variations in Annealing Temperatures on the Brinell Hardness Numbers and Machining Properties of Stampings.*

The effect of annealing stampings for two hours at 550° C. and 650° respectively.

	Stampings re-annealed at 650° C.					Stampings re-annealed at 550° C.			
No.	Hardness (before).	Variation from Average.	Hardness (after).	Variation from Average.	No.	Hardness (before).	Variation from Average.	Hardness (after).	Variation from Average.
A1	81·2	2·4	80·0	4·5	D1	67·0	-12·7	67·6	-10·1
2	76·4	-2·4	78·2	-0·3	2	81·2	1·5	83·6	5·9
3	78·8		77·6	-0·9	3	73·2	-6·5	73·4	-4·3
4	94·8	16·0	88·4	9·9	4	69·4	-10·3	68·8	-8·9
5	74·6	-4·2	77·0	-1·5	5	83·0	3·3	78·3	0·6
6	73·8	-5·0	77·0	-1·5	6	89·8	10·1	87·2	9·5
B1	77·0	-1·8	81·2	2·7	E1	77·0	-2·7	74·0	-3·7
2	74·6	-4·2	76·4	-2·1	2	73·0	-6·7	69·4	-8·3
3	76·4	-2·4	75·8	-2·7	3	82·4	2·7	81·8	4·1
4	76·4	-2·4	79·4	0·9	4	81·8	2·1	79·4	1·7
5	73·6	-5·2	73·2	-5·3	5	84·8	5·1	82·4	4·7
6	79·4	0·6	79·4	0·9	6	83·0	3·3	79·4	1·7
C1	81·2	2·4	78·8	0·3	F1	80·6	0·9	78·8	1·1
2	83·0	4·2	83·0	4·5	2	76·4	-3·3	74·0	-3·7
3	81·2	2·4	81·8	3·3	3	80·0	0·3	77·0	-0·7
4	78·2	-0·6	74·0	-4·5	4	86·6	6·9	89·0	11·3
5	78·2	-0·6	77·0	-1·5	5	84·8	4·1	80·6	2·9
6	80·6	1·8	75·8	-2·7	6	80·6	0·9	73·6	-4·1
Av.	H.78·8		78·5			79·7		77·7	
Av.	+Diff.	4·26		3·29			3·42		4·35
Av.	-Diff.	3·20		2·30			7·05		5·47

The above investigations will now be considered in order.

1. The first investigation serves, incidentally, to show how unreliable a criterion are the opinions of machine operators of the hardness of such stampings as pass under their notice in the shops. The difference of 36·4, between the hardest and the softest of this lot, all of which were stated to be hard to machine, is surprising, particularly as cases had been noted of stampings having a hardness number of 95 being termed " soft."

It will be seen that the variation in hardness is considerably reduced by annealing for an hour at either 650° C. or 780° C. with subsequent cooling in the furnace ; whereas this variation appears to tend to increase when quenching follows a short soaking at either of the above temperatures. The noticeable reduction in hardness variation obtained by heating to 780° C. for one hour and cooling in the furnace led to the preliminary suggestion being made that all stampings prior to machining be treated thermally in this manner. Dr. Stead's paper had not then been consulted, hence his statement as to the deleterious effects of annealing at temperatures between 750° C. and 800° C. had not been noted. As no mechanical tests were undertaken in connection with these particular trials, no definite conclusion can be drawn as to the effect of one hour's annealing at this " dangerous " temperature, but it is thought that structural re-arrangement would not have proceeded so far in this time as to have developed the weakness noted in Dr. Stead's paper.

Another point worthy of note is the evident influence of the quantity of the β constituent present in the stampings on the Brinell hardness numbers of the same. No explanation can, however, be granted for the remarkable figures obtained in the case of stamping No. 4A.

2. The second investigation was made with a view to a discovery of the most suitable annealing temperature prior to machining. Hence the division of the thirty-six stampings into six groups.

For correctly interpreting the results obtained, which are fully tabulated in Table C, it appears desirable to eliminate from the above table all those stampings whose Brinell hardness numbers prior to annealing were either above 90·0 or below 80·0. By tabulating those stampings having hardness numbers within

the above limits in the order of their initial hardness numbers, and by estimating the average final hardness numbers of those stampings belonging to each lettered batch (the letters referring the stampings, as in Table C, to definite annealing temperatures), some idea as to the most suitable temperatures for annealing can be ascertained.
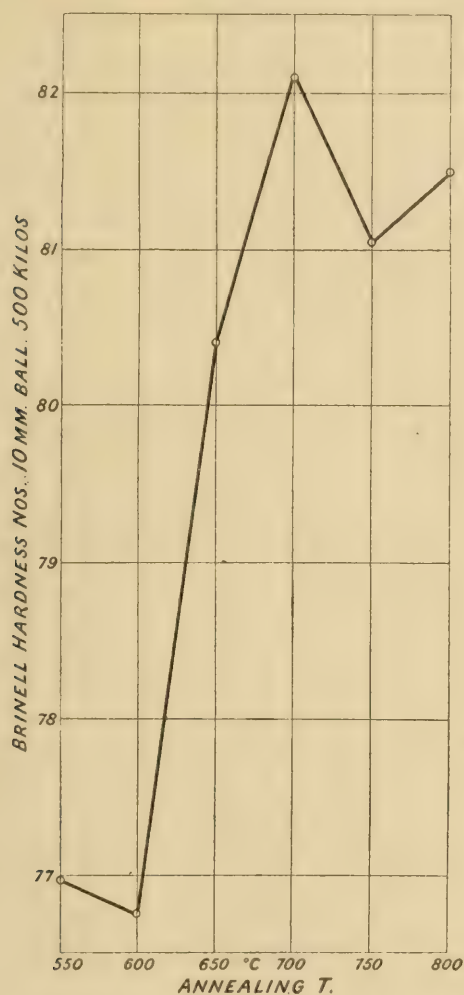

Fig. 2.

From Table C those stampings bearing identical letters and which possessed Brinell hardness numbers between 80·0 and 90·0 prior to annealing have been taken and their average final hardness numbers estimated. The relation of the Brinell hardness number to the annealing temperature is given in Fig. 2.

Further inquiry into this subject might well be made, but it is considered that the evidence in favour of the belief that the most suitable annealing temperatures are below rather than above 600° C. is fairly satisfactory, in spite of the somewhat small number of cases investigated.

3. The third investigation was made to test the conclusions arrived at as a result of the last investigation. As already stated, batches A to C were re-annealed at 650° C. and allowed to cool in air, and batches D to F were re-annealed at 550° C. and likewise cooled. The results of this experiment are shown in Table D. It will be seen that at least some confirmation is given of the belief that annealing temperatures of less than 600° C. are more suitable than those greater than 600° C. A further point which is worthy of note in connection with the examination of Table D is that of uniformity of hardness. Uniformity of hardness is, possibly, of more import than actual hardness in the workshop, especially in those cases where small tools are being employed, since variations in the hardness of the metal are bound to cause trouble with the tools. It will be seen from the table that whereas the Brinell hardness numbers of the first three lots have been reduced on the average by only 0·30 (0·38 per cent.), those of the second lot have been reduced on the average by 2·0 (2·5 per cent.). By annealing at 650° C. the average variation above the average hardness has been reduced from 4·26 to 3·29, and those below the average hardness from 3·20 to 2·30, whereas by annealing at 550° C. the average variation in hardness above the average has increased from 3·42 to 4·35, and those below the average has decreased from 7·05 to 5·47. There appears, therefore, to be a greater tendency towards uniformity in the first than the second case, but the difference between the two cases is negligible. It is not considered that a greater tendency towards uniformity in hardness can be claimed for a particular annealing temperature. The length of time of annealing is doubtless an important factor in this connection; longer annealing periods would doubtless involve greater uniformity of structures and, hence, of hardness.

(e) The Influence of the Mechanical and Physical Condition of the Machining Tool on the Machining Properties of Stampings.

To ascertain as far as possible the effect of the tool on the machining properties of stampings, the stampings tabulated in Table C were divided into three groups of twelve stampings. The first group consisted of those stampings marked with the figures 1 and 2, *e.g.* 1A, 1B, 1C, &c., and 2A, 2B, 2C, &c., the second group consisted of those marked 3 and 4, and the third of those marked 5 and 6. The stampings of each group were milled in order, the length of channel milled in the stamping being the same in each case. The milling was performed by causing the stamping to move under the rotating milling tool in a definite direction by means of a definite and constant weight of 9 lb. The time occupied by the milling tool in cutting the slot was noted in each instance. Operations on each group were started on numbers 1A, 3A, and 5A, and concluded on numbers 2F, 4F, and 6F respectively. For machining each group one tool was employed, which was not touched in any way until that group was completed. When the machining of a given group was completed, a new tool was placed in position, and the stampings of each group were machined on another face ; this time, however, in the reverse order from the first, *i.e.* starting with numbers 2F, 4F, and 6F, and ending with numbers 1A, 3A, and 5A. The time now occupied in machining each stamping was noted. In certain cases abnormal milling times were registered. For example, the time occupied in milling 4F for the second time was 144 seconds. It was found that the tool was soft, hence it was replaced by a new one for the purpose of cutting numbers 4E and 4D, &c. Again, an abnormal figure was obtained during the second trial on 6D. The milled slot was found to have been cut too deeply. In the case of number 6F, the second machining only occupied 33 seconds, and before it had begun to cut number 6E, the tool broke at the shoulder. It was therefore substituted by another cutter. Numbers 2E and 2F were machined with the cutter that had been used for the tooling of the first group from 1A to 2F. It was discarded before 2D was machined. The hardness figures,

times, &c., are tabulated in Table E. The mean of the two

TABLE E.—*The Influence of the Mechanical and Physical Condition of the Machining Tool on the Machining Properties of Stamping.*

No.	Hardness.	Times, Seconds.		
		Down.	Up.	Average.
1A	81·2	34·0	57·5	45·75
B	77·0	32·5	50·5	41·50
C	81·2	36·5	53·5	45·00
D	67·0	29·0	41·0	35·00
E	77·0	34·5	44·5	39·50
F	80·6	31·0	35·0	33·00
2A	76·4	39·5	43·5	41·50
B	74·6	38·0*	35·0	36·50
C	83·0	50·5	40·0	45·25
D	81·2	56·0	35·0	45·50
E	73·0	46·5	52·0	(A.)
F	76·4	48·0	48·5	(A.)
3A	78·8	34·0	29·0	31·50
B	76·4	36·0	30·5	33·25
C	81·2	47·0	39·0	43·00
D	73·2	37·0	34·5	35·75
E	82·4	39·0	29·0	34·00
F	80·0	38·0	27·0	32·50
4A	94·8	67·0	37·0	52·00
B	76·4	62·0	25·5	38·75
C	78·2	52·0	28·0	40·00
D	69·4	46·5	26·0	36·25
E	81·8	60·0	26·0	43·00
F	86·6	63·0	144·0	(B.A.)
5A	74·6	45·0	72·0	58·50
B	73·6	46·5	66·5	56·50
C	78·2	42·5	72·5	57·50
D	83·0	56·0	99·0	77·50
E	84·8	49·5	85·0	67·25
F	84·8	51·5	82·0	66·75
6A	73·8	65·5	82·5	68·50
B	79·4	48·0	73·5	60·75
C	80·6	47·0	79·0	63·00
D	89·8	52·5	101·0	(D.A.)
E	83·0	52·5	62·5	57·50
F	80·6	50·0	22·0	(B.A.)

Routers used.
1. 1A to 2F and returning, 2F and 2E.
2. 2D to 1A.
3. 3A to 4F.
4. Returning, 4F (Soft).
5. 4E to 3A.
6. 5A to 6F.
7. Returning, 6F (Broke).
8. 6E to 5A.
G. Slot narrow to gauge.
A. Unreliable figure.
B. Tool failed.
D. Slot deep to gauge.

channelling times observed in all the normal cases were calcu-
lated and the relation between the Brinell hardness numbers

* (G.A.)

and the channelling times are shown in Table E and in Fig. 3 herewith.
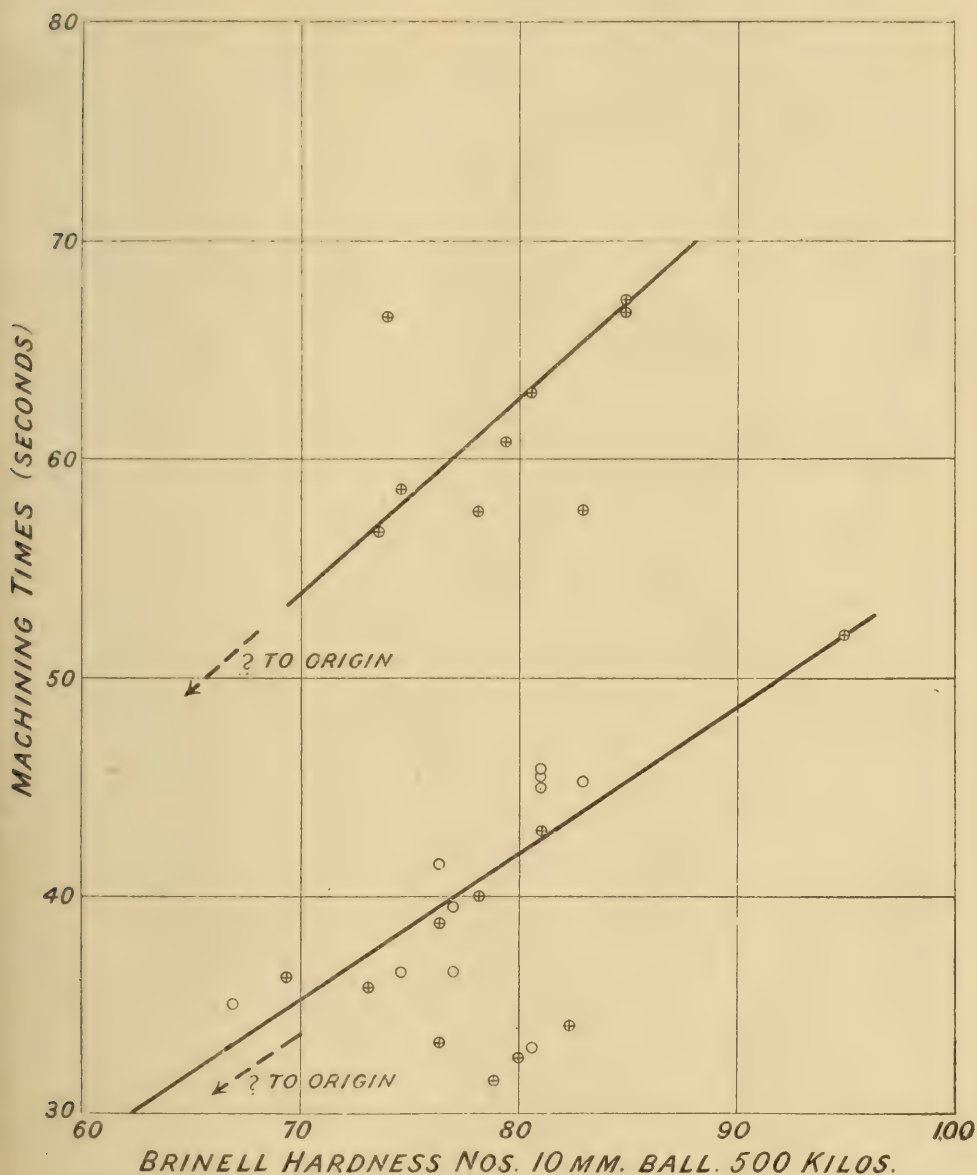

FIG. 3.*

An examination of Table E readily reveals the blunting effect of machining on the tool. For example: the first tool employed occupied 34 seconds in channelling stamping 1A, with a Brinell hardness number of 81·2, while the same tool

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* It is a debatable point whether these curves should be drawn parallel to one another. It seems likely that they would meet at a point on the hardness base.

later occupied 36·5 and 56·0 seconds in cutting stampings 1C and 2D respectively, though these stampings had the same Brinell hardness numbers as stamping 1A. An examination of the graph shows that the condition of the tool (its hardness, form, &c.) exerts considerable influence on the machining times, apparently without greatly altering the ratio between the two factors here under consideration. The latter clause of the last sentence must, however, be accepted with reserve, since the conditions of the experiment and the narrowness of the hardness range (and therefore of the composition) of the alloys tested do not tend to accurate conclusions as to the actual slopes or forms of the curves obtained.

This concludes the first, or negative portion of the research. The results obtained are summarized below.

Summary.

(i.) The Brinell hardness numbers of the copper-zinc alloys in the range 55 per cent. to 65 per cent. of copper are inversely proportional to the copper content. This fact might be made of use in foundries where scrap, swarf, &c., of unknown origin are being melted into ingot form ; a rough ball test would give a close approximation of the copper content of any given ingot, and subsequent mixing could be arranged accordingly.

(ii.) Other things being equal, variations in the temperature of casting of a given set of stamping castings are without influence on the Brinell hardness numbers of the finished stampings.

(iii.) Variations in the temperature of the castings and, less so, of the die, tup, &c., at the time of stamping are the cause of considerable variations in the mechanical and physical condition of the untreated stampings.

(iv.) The most suitable annealing temperatures for stampings are below, rather than above, 650° C.

(v.) The machining times of the stampings are as dependent on the condition of the tools as on the Brinell hardness numbers of the stampings. It seems likely that over the short range dealt with that the machining times vary directly with the Brinell hardness of the stampings.

The second line of investigation took the form of an inquiry into the relation between the chemical composition and certain of the physical and mechanical properties of the range under consideration.

To satisfy ourselves of the width of our range a series of chill castings 2 in. in diameter and 2 in. in height were prepared by melting trade bar of known copper content and by adding suitable quantities of copper or zinc. The castings when cold were annealed for $1\frac{1}{2}$ hours at a temperature of 650° C. In every case the castings were found to be perfectly sound.

Further, a set of twelve stampings was examined. These also were annealed at 650° C. prior to test in order to bring the same, as far as possible, into the same condition, constitutionally, as the chill castings.

The complete analyses of the whole series of these alloys are given in Table F.

TABLE F.—*Complete Analyses of Stampings and Castings.*

No. of Casting.	Copper. Per Cent.	Lead. Per Cent.	Iron, Aluminium. Per Cent.	No. of Stamping.	Copper. Per Cent.	Lead. Per Cent.	Iron, Aluminium. Per Cent.
1	55·9	0·85	0·10	1A	57·2	0·73	0·34
2	56·1	1·04	0·06	2A	57·3	0·96	0·39
3	57·1	0·90	0·16	3A	57·8	0·95	0·46
4	57·1	0·91	0·15	4A	57·9	0·86	0·44
5	57·5	0·94	0·14	5A	58·0	0·88	0·38
6	58·4	0·78	0·05	6A	58·4	1·15	0·15
7	59·0	0·95	0·06	7A	58·6	0·81	0·17
8	59·0	0·96	0·13	8A	60·4	1·34	0·41
9	61·1	1·08	0·15	9A	60·4	0·63	0·54
10	62·0	0·65	0·11	10A	60·8	0·74	0·24
11	63·4	0·45	0·04	11A	60·8	1·07	0·11
12	64·3	0·60	nil	12A	61·9	1·07	0·05

The properties that have been studied with regard to their variation with the copper content (and, therefore, Brinell hardness) of the alloys of this range, 55 per cent. copper to 65 per cent. copper, are as follows :

(*a*1.) Tenacity ; (elongation).
(*b*1.) Relative power absorbed in machining.
(*c*1.) Relative time occupied in machining.

(a1.) *The Relation between the Tenacity, &c., and the Composition of Brass.*

This relation has already been carefully considered by the following investigators—Thurston (1884), Charpy (1886), and Roberts-Austen (1897).

The results obtained by the author are detailed in Fig. 4. All these tests were made on specimens $\frac{1}{50}$ square inch area, this size of specimen being chosen as it was the largest that could be conveniently turned from the castings and stampings under examination. The sequence of the values for tenacity is fairly uniform, but that for percentage elongation is somewhat irregular. In both cases, however, the curves obtained agree fairly well with those based on the results of the investigators already mentioned.

(b1.) *The Relation between the Relative Power absorbed in Machining and the Composition of Brass.*

For the purpose of investigating the above relation a drill test was carried out. A $\frac{1}{2}$-in. drill was loaded with a definite and constant weight, and the watts absorbed during the operation of drilling each of the series of castings Nos. 1 to 12 were calculated after the observations had been made of the average voltage and amperage registered during trial. Five separate estimations were made in connection with each casting. The average values in watts for the complete series are shown in Fig. 5 plotted as ordinates with compositions as abscissæ.

(c1.) *The Relation between the Relative Time occupied in Machining and the Composition of Brass.*

This relation has been ascertained by observing the time in seconds occupied in drilling a hole of definite depth under a definite and constant load. These trials were not carried as far as it was desired to do. In some cases only two results were obtained on each casting, hence there is much to be desired in the way of further investigation. The average values obtained are plotted against composition in Fig. 6. It will be noted that the curve

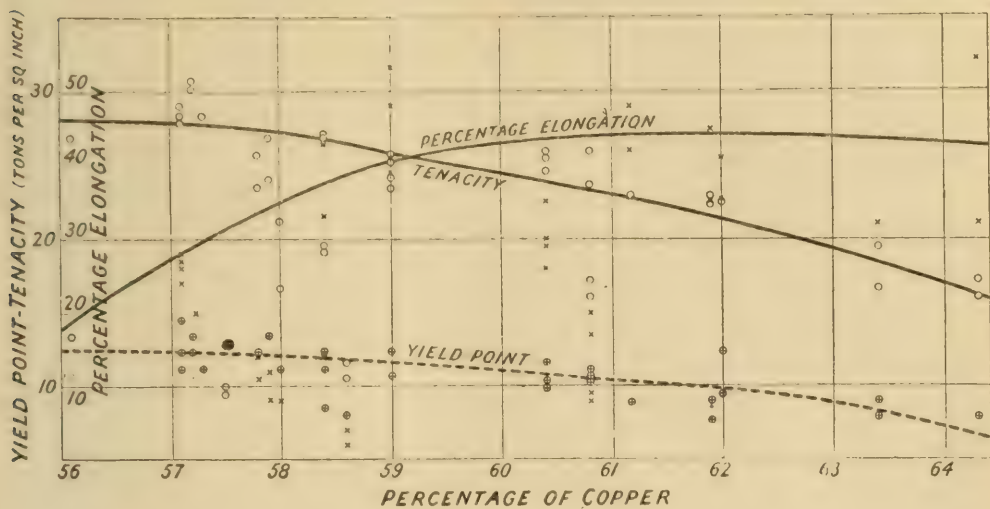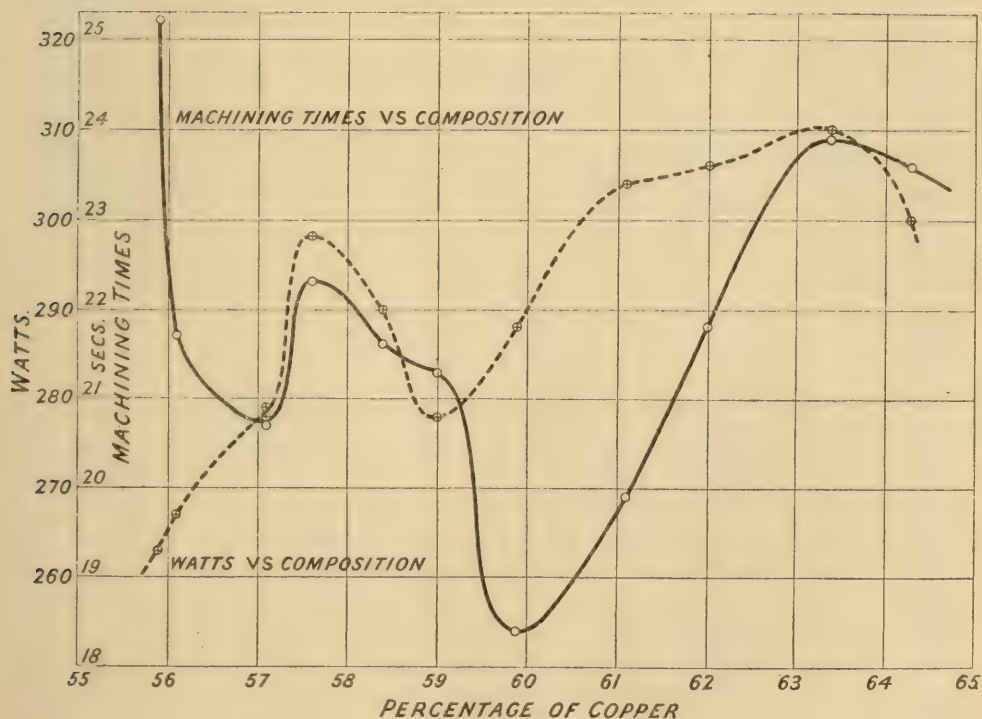approaches in general outline to that showing the relation between

FIG. 4.

the relative power absorbed in machining and the composition of
these brasses. One noticeable discrepancy there is in the case of

FIGS. 5 and 6.

the No. 1 alloy, containing 55·9 per cent. of copper. In the power-

composition curve the power value for this alloy is comparatively
low, while in the time-composition curve the time value for the
same is remarkably high.   The low machining time of the 60 : 40
alloy is worthy of note.

The results depicted in this curve certainly upset the pre-
conceived notions as to machining times which are mentioned
in the first paragraph of this paper, and bear out very fully the
findings of Kessner (*Carnegie Scholarship Memoirs*, vol. v.)
as to the relation between the machining times and Brinell
hardness numbers.

One feature of the series considered and worthy of note here is
the type of turning obtained in machining.   There is a distinct
change in the type of turning produced from these alloys at a
percentage of copper of about 59.   In the case of alloys con-
taining a less percentage of copper than 59 there is a tendency for
long, thin, ribbon-like turnings to be produced.   In the case of
alloys containing more than 59 per cent. of copper there is a
tendency for strong spiral-shaped turnings to form.   At about
59 per cent. of copper short, chippy turnings are predominant.
This fact may account for the low power figures of the alloys of
about this percentage, since less choking of the drill would be
noticed if short, chippy material was being cut away by the same.
The above observations concerning the type of turning produced
from these alloys appear to apply almost without exception, even
in the presence of lead up to about 1 per cent.

Summary of Research.

The most important principle established as a result of this
research is the necessity of attaining uniformity of chemical
composition in the manufacture of stampings subsequently to
be machined if uniformity of mechanical and machining properties
are to be attained in the final stages of the process.   The fact
that there is a uniform increase in hardness of brass with a uniform
decrease of copper percentage is the sufficient, though not the
sole, argument in support of the above proposition.   The irregu-
larity in the machining properties as evidenced in the second part
of the research are well worthy of note in this connection.

The second matter worthy of consideration is that an annealing

subsequent to stamping is desirable if absolute uniformity of mechanical and other properties is required.

The third point of note is that the research witnesses to an important fact of workshop experience, namely, that the 60 : 40 alloy is the most universally successful of brasses as far as mechanical, physical, and machining properties are concerned. The results obtained in the power and time-composition experiments are very enlightening on this point, as are also the tenacity, &c., experiments.

The points established in the first portion of the research and summarized above need no further recapitulation.

The author desires to express his thanks to the authorities of the Royal Arsenal for their permission to publish much of the above.

NOTE

ON THE MACHINING PROPERTIES OF BRASS.*

By OWEN WM. ELLIS, B.Sc. (BIRMINGHAM).

IT has been noted that cold-rolled 60 : 40 rods having Brinell hardness numbers as high as 140 machine almost as readily as stampings (hot forged) of similar composition having Brinell hardness numbers of approximately half the above value. The fact that brass stampings having hardness numbers much above 70 are difficult to machine has been noted in a paper by the author.

This difference in machining properties can, it is believed, be explained by a consideration of the microstructures of the materials in question.

1. *Normal Stampings* (*hot forged and unannealed*).—The microstructure consists of a matrix of the β constituent containing α crystallites possessed of no definite orientation. Similar types of structure are to be observed across whatever section of the stamping may be cut.

2. *Rolled Bar* (*cold rolled*).—The structure is somewhat similar to the last in sections which are normal to the axis of the bar, but in sections parallel to the axis of the bar elongated and almost continuous crystallites of the β constituent are to be observed set in a matrix of the α constituent.

3. *Hard Stampings* (*hot forged*).—The result of a limited number of observations leads to the belief that in the majority of cases the structure is of the Widmanstätten character.

For purposes of explaining the differences observable in the machining properties of types 1 and 2, it is convenient to imagine two cylinders of jelly, one throughout whose mass numerous irregularly shaped rods of substance harder than the jelly are indiscriminately scattered ; the other throughout whose mass are distributed somewhat longer rods, of more regular outline and of similar substance to the short rods already mentioned, but arranged parallel to the axis of the jelly cylinder.

If a section of either of these jelly cylinders be taken at right angles to the axis of the same, the sections will exhibit, in many cases, very similar types of structure. It would be expected, therefore, that other things being equal, in cutting through either of these cylinders at right angles to their axes, since the amounts of hard material to be removed

in both cases are practically equal in quantity, there would be little difference in their cutting times. Further, it is natural to suppose that if the cylinders were subjected to plastic deformation, the second cylinder would offer the greater resistance, owing to the more stable mechanical arrangement of the hard substance.

The general structure of the first cylinder corresponds with that of a normal stamping, that of the second with that of a rolled rod. From the above, therefore, it will be seen by analogy that one might expect a rolled rod to have machining properties equal to those of a stamping and yet to possess a higher Brinell hardness number owing to the more stable arrangement of the structure.

The above suggestions are of interest when viewed in conjunction with the results of a number of tests made by Professor Arnold on special steels, which are recorded in vol. xciii. p. 104 of the *Journal of the Iron and Steel Institute*. In the paper referred to it is shown that the cutting properties of special steels are not related to the Brinell hardness numbers of these steels.

DISCUSSION.

Mr. R. T. Rolfe (Bedford), in opening the discussion on Mr. Ellis' communications, said that he thought one of the author's most interesting conclusions was that relating the Brinell hardness figures of the 60 : 40 stampings to the machining times. That this relation appeared to hold good only over a certain limited range was not surprising, in view of the differences between the operations of multiple cutting on a milling machine and brinelling. Milling was a form of abrasion, of course on a much larger scale than most of the usual types, such as that of the sand-blast, but still a sort of abrasion, the simile becoming more clear if one thought of a blunt milling cutter. Some of the material was deformed to the point of fracture, while the rest was deformed in varying degrees from nil to maximum. Some indentation must take place before any material could be removed. Abrasion had been described as approximately tangential indentation. The amount of plastic deformation of the residual metal after a milling cut had been taken, especially with a light cut at high speed, was comparatively smaller than the deformation which took place in brinelling. Again, in milling shear stress largely came into play, which was not the case in brinelling. In the latter, a compressive stress was applied, no material was removed, but there was a varying deformation as before from nil to a maximum. There was obviously some relationship between the two operations, but owing to the differences there might be between the compressive strength and the shear strength of a material, it was obvious that the Brinell figure might sometimes be quite misleading. In the case of a number of similar alloys, the one having the greatest compressive strength was not necessarily the one having the greatest shear strength, in which case the Brinell figure might be no indication of the machinability. He had had no experience of 60 : 40 brass stampings, but he thought it might be of interest to the members if he quoted, as an example from practice, the case of phosphor bronze of Admiralty composition, consisting of 85 parts of copper and 15 parts of phosphor-tin, the latter nominally containing 5 per cent. of phosphorus. This alloy sand cast, with a Brinell figure of 90 to 105, machined with great difficulty, whereas chill cast, with a Brinell figure of 110 to 125, it machined with the utmost ease. Again, a certain air-hardened steel, in a 55 to 60-ton state, with a Brinell figure of 255 to 269, was harder to machine than another oil-hardened steel in a 70-ton state with a Brinell figure of 318. If the former steel were heat-treated to give a Brinell figure of 318, it was very much harder to machine than the other, which showed that in some cases the Brinell figure might be

no indication of the machinability. These examples were not given with the object of detracting in any way from the merits of the research carried out by the author, but merely to point out that the conclusions arrived at should be limited strictly to the case in question. In that particular case, the value of the relationship, and its application to the standardization of methods of manufacture had, he thought, been amply demonstrated.

Mr. F. JOHNSON, M.Sc. (Birmingham), said that he desired to raise a few questions in connection with the author's most interesting paper. In the first place, he desired to ask whether the author had found any difference in hardness of the specimens when the test was taken in different positions. For instance, did the centre of the stamping give the same Brinell hardness as the edge ? The author referred on p. 29 to the fact that a batch of stampings was heated to 780° C. for five minutes and then quenched. He would like the author to make it clear whether the stampings were retained definitely at that temperature for five minutes, and whether he took the temperature of the stampings or of the furnace. He desired to confirm what the author said about the confusion that existed in the minds of some machinists as to what was hard and what was soft in the machine. It was generally found that machinists described a ductile and tenacious material as hard, whereas mineralogically it was really soft. On p. 34 the author referred to a temperature of 600° C. as being specially applicable for annealing stampings. He had not the equilibrium diagram in front of him, but he rather thought at that temperature a stamping of 60 : 40 composition was well below the transformation point, so that it was really a question of incipient aggregation and relief from strain rather than any constitutional change which was brought about. In the summary of the conclusions set out on p. 38, the author suggested, in the first place, that a rough ball test would give a close approximation to the copper content of any given ingot, and that subsequent mixing could be arranged accordingly. In that connection he thought it was necessary to sound a note of caution. That suggestion would only have to be applied to castings made from pure metals. The introduction of impurities would upset the test, and other things, such as the temperature of the pouring, the temperature of the mould, and the size of the ingot, would also have to be standardized before such a test could be taken as even an approximation to the copper content. Unfortunately there was a considerable variation in the analyses given by the author in Table F. For instance, the lead varied from 0·73 to 1·34, nearly 100 per cent. difference, and in another case from 0·45 to 1·08 ; while the iron varied from 0·06 to 0·15 and from 0·05 to 0·46. Those were unfortunate variations which must vitiate the results to some extent, although perhaps not to a very appreciable extent. As the author had included aluminium with iron, the vitiation was somewhat more real than apparent, because of the

highly strengthening and hardening effect of aluminium as compared with any of the other impurities mentioned. He desired to ask the author how the yield points were taken on the small specimens. The statement was made that specimens of only $\frac{1}{50}$th of a square inch were possible, but test-pieces of that length he (Mr. Johnson) had been able to prepare with an area of $\frac{1}{20}$th of a square inch, which was a rather more satisfactory size. In the graphs given by the author on p. 41 containing the variations of elongation, tenacity, and yield point, he thought the results for not only the castings but the stampings were given. He desired to suggest to the author that it would be preferable to have one graph for stampings and one for castings. He was of that opinion for the reason that he had found considerable variations in castings and stampings of the same composition. In one case of a chill casting of 56·6 copper, 1·17 lead, and small traces of other impurities, there was a yield point of 13·6, a break of 25·25, and an elongation of 9 ; whilst the stamping had a yield of 11, a break of 24, and an elongation of 19. He thought it improbable that annealing would bring the casting into exactly the same condition as the stamping. A large meed of praise was due to the author for having been able to do the work at such a time.

Professor T. Turner, M.Sc., Vice-President, said that the author, who was one of his old students, had investigated a subject which was of very considerable importance at the present time. The machining of brass had always been an important subject, but it had never been so important in this country as it had been during the past two or three years. It was not a subject on which he, as a metallurgist, could speak with any authority ; it was one with which the mechanical engineer must deal ; but, judging from the parts of the research which he could check by his own knowledge, he was of the opinion that the author's results were accurate. He presumed, therefore, that if the half was correct it was probable that a great deal of the residue would also be correct. The author had referred to the question of the hardness of the alloys, and to the fact that in the range with which he experimented it was possible to determine the percentage of copper approximately by the Brinell hardness. That was only true, as Mr. Johnson had stated, provided other elements were not present ; and, further, it was only true within quite a limited range, because, as the experiments conducted some years ago by Mr. Murray in the Birmingham Laboratory showed, there was not a regular curve in the hardness of the copper-zinc series. If the proportion of copper increased, there was often a fall in the hardness. The hardness increased as the copper fell within the range of the author's experiments ; but with more copper the hardness increased again, and afterwards it fell away before the copper end of the series was arrived at—*i.e.* it was a wavy curve. So that it was only within a certain range, even with pure materials, that the proportion of copper corresponded with the hardness. It had

been pointed out by Mr. Rolfe that one would not expect to find the relationship between the machining properties and the Brinell hardness regular and concordant. In that connection he desired to refer to some very interesting experiments recorded by Professor Arnold, at a recent meeting of the Iron and Steel Institute. Professor Arnold, who was then dealing with the question of the Brinell hardness and the cutting hardness of steel tools, showed that the Brinell hardness did not give any indication of the cutting properties of steel. Conversely, the Brinell hardness did not necessarily give any indication of the machining properties of the steel. Brinell hardness, in a ductile material, did give an indication of the yield point of the steel, and to some extent of the tenacity of the steel. One of the previous speakers had said that in the Brinell hardness shear was not present ; but in the Brinell hardness the hole was made as a result of shear. If it were a crystallized material it could not be deformed without crystal shear, so that it was not correct to say that a shearing-strain was not present in such a case.

Dr. WALTER ROSENHAIN, F.R.S., Member of Council, said that he desired to refer to the explanation put forward by the author concerning the hardness and machining properties of a cold-rolled or cold-drawn bar and of a stamping or casting having the same Brinell number. Although the author's explanation was ingenious, and no doubt covered part of the truth, he felt there was something more to be said in connection with it. He wished to direct attention to the fact that the Brinell hardness of cold-worked material arose from a different cause from the Brinell hardness of the untreated casting or stamping. The hardness of a stamping or casting might be described as structural hardness due to the arrangement of the alpha and beta constituents, the soft and relatively hard constituents of the brass. On the other hand, the hardness of the cold-worked material arose largely from the strain hardness due to the cold-working of the alpha constituent and was therefore of a different character. First of all, it was not isotropic, *i.e.* the hardness was different in different directions, just as it was found that a substance which had been strained in tension and hardened against further tension by that strain, had been softened against compression. In the same way he thought it probable that if the Brinell ball test on a cold-worked bar were made in a longitudinal plane and also in a transverse plane, somewhat different figures would be obtained. Another point that must be borne in mind was the temperature effect in the case of strain hardness. The actual point of contact, of cutting, where a tool acted upon a metal, was always hot. That was well known, because the limit of cutting speed was due to the softening of the steel tool by the heat generated, even when oil or water cooling was applied. That heat was quite sufficient locally to produce softening and to remove a great deal of the strain hardness at the point of cutting, whereas the structural hardness due to the arrangement

of the alpha and beta could not be affected by any cause of that sort. For that reason it might be anticipated that there would be a considerable difference between the behaviour of two substances of the same Brinell hardness, one due to the structural condition and the other due to strain.

Mr. F. E. ROBINSON (Woolwich) said that he desired, for the benefit of the members and visitors, to give some information in connection with the tests that had been carried out by the author. The tests on which most of the information contained in the paper was based were carried out at his (Mr. Robinson's) request in connection with a certain important component of gun ammunition. A considerable difficulty was being experienced in obtaining uniform results from a component which had to be made to very fine limits. The operation was a routing operation ; metal had to be removed at a high rate of speed and accurate results had to be obtained : the work had to gauge correctly. It was found impossible to get the work to gauge the same ; tools frequently broke when using the same feed on certain stampings, while in other cases they gave good results. In other cases with some stampings the tools became blunt very rapidly, although to commence with they were perfectly sharp and uniformly hardened and tempered. The author carried out his experiments in a most commendable manner, with the result that practically all the difficulties that had been experienced were overcome. Put in a nutshell, if it were desired to get good and accurate work when dealing with brass, it was necessary to adhere as closely as possible to a 60 : 40 alloy. He did not think the influence of iron and aluminium had very much to do with the matter at all. In connection with the note on the 60 : 40 rod and the 60 : 40 stamping most marked results were obtained. So much difficulty was experienced at one time that a large number of the components had to be made from rod metal instead of from stampings. Rod metal always gave good results, and stampings always gave indifferent results until the reason for the difference was ascertained. The author then discovered that the difference was due partly to the departure from the 60 : 40 alloy, and partly on account of the different construction and arrangement of the crystals in the stamping and the metal rod. Dr. Rosenhain had referred to the question of the heat at the point of cutting. In the experiments which were carried out, the point of the tool could not get very hot. The little routing tools that were used had a constant supply of oil at pressure. In the case of some of the alloys the cuttings were not washed out, but in the 60 : 40 alloy the cuttings were rapidly removed. Since the author's experiments had been carried out, one most important discovery had been made which had not been realized before, namely, the very great importance of cutting at the highest possible cutting speed if accurate drilling and routing was required in brass. With a stiff machine and a very high speed of rotation, the variation in the alloy could be got over to a very

large extent. It was possible to allow a greater departure from the
60 : 40 alloy if the above-mentioned conditions were fulfilled.

Mr. M. T. MURRAY, M.Sc. (Birmingham), said that the paper dealt
with a subject which was of vital interest to manufacturers, and for
that reason he thought the thanks of the members were due to the
author, to whom every encouragement ought to be given to continue
his work on the same lines, with the object of arriving at further
information on the very important point under consideration. That
was particularly so in view of the fact that every manufacturer of
brass rods would endorse the author's remark on p. 32, to the effect that
the opinions of machine operators were entirely unreliable as a criterion
of the hardness of the metal with which they were dealing. He had
frequently been told by machinists of brass rods that a particular
rod was too hard to machine, when it had subsequently been proved
that the rod was not hard at all, but perfectly soft. He desired to
take up the point Dr. Rosenhain had made with regard to the ex-
planation of the differences in the speed of machining of what might
be called, non-technically, "naturally hard" material, and "work-
hard" material. He had recently had some practical experience of
that sort of thing. For instance, it was found in a mild manganese-
bronze alloy which had been made to pass a test of about 20 tons yield,
30 tons break, and 20 per cent. elongation, that its scleroscope hardness
was extremely high. But exactly the same results might be obtained
by putting work upon another bar of perhaps merely 60 : 40 composition,
or a variation of the 60 : 40 composition. Exactly the same test and
Brinell hardness could be obtained, and it would be found that the
bar which had been work-hardened machined about three times as
quickly as the bar which was naturally hard. That had been proved
in practice in his experience in connection with hundreds of tons of
material. There were a great number of technical points that he would
refer to, but in view of the shortness of the time, he would only
like to draw attention to the author's remark on p. 32 : " It will be
seen that the variation in hardness is considerably reduced by annealing
for an hour at either 650° C. or 780° C., with subsequent cooling in
the furnace ; whereas this variation appears to tend to increase when
quenching follows a short soaking at either of the above temperatures."
Might not that be due to the fact that the alloys with which he was
dealing varied by 2 per cent. of copper (from 59 to 61, as was stated
on p. 29), and that therefore in the quenching of the alloy very different
proportions of beta were obtained, whereas in the slowly cooled alloy
different proportions were obtained certainly, but they would not be
by any means so widely different as under the former conditions,
since material quenched from 650° C. would be quenched from the
$a+\beta$ region in Shepherd's diagram, while that quenched from
780° C. would probably consist, in some cases, wholly of β.

Mr. O. W. ELLIS, in reply, thanked Mr. Rolfe for the very interesting remarks he made with regard to the relation between Brinell hardness and milling. Professor Turner had referred to the relation between compression and shear; the author thought his remarks, coupled with those of Mr. Rolfe, might serve to put the position as it really existed. Shear, no doubt, was a factor in Brinell hardness, but he thought the compressive effect rather limited the shearing action of the ball after the same had been pressed down a certain distance. With regard to Mr. Johnson's remarks, the Brinell hardness was taken at a number of different positions on the stampings, and varied very slightly in most cases. Not less than two indentations were made on all the stampings, but that number was exceeded on some of them, and there was very little variation in those tested in the latter manner. He had been asked a question with regard to the annealing at 780° C. The stampings were placed in a furnace at 780° C. for five minutes, and were not heated at 780° C. for five minutes.* With regard to the effect of impurities on the ball test, it would be seen on p. 26 that the variation in the percentage of lead in the alloys was from 0·45 to 1·34. The percentage of iron and aluminium varied about 0·2. There was not more than about 0·1 per cent. difference in either element, though this, certainly, would have a slight effect in changing the Brinell hardness.† It should be noted that the curve that the author had drawn in Fig. 1 was very approximate. If the suggestion he had put forward as to the use of the Brinell hardness test in the foundry was thought to be of any value, two lines might be drawn for the limiting values of the copper content corresponding to given hardness numbers on the diagram, between which most of the points that were given thereon lay. The author had been asked a question as to the method of taking the yield point. It was taken with a small extensometer, such as was described in a paper read by Mr. G. H. Roberts on "The Co-ordination of Engineering Research." ‡ It was a small instrument in which all the backlash was taken up, the elongation being amplified by means of a suitably arranged rack and pinion which served to operate a needle on a dial. The yield point was taken as the load at which a permanent set of two-thousandths of an inch was observable after the load had been removed. He could not here state the length of specimen, but it was based on Unwin's formula for $\frac{1}{5.0}$th of a square inch area (0·566″). He agreed with what Dr. Rosenhain had said with regard to the constitutional and strain hardness of the bars and stampings. The suggestion that he (the

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* The stampings in question were less than half an inch in thickness, and attained the temperature of the furnace in less than five minutes.

† These differences were doubtless sufficient to account for the hardness differences observable in the author's curve. This fact did not of itself render the suggested mode of discrimination useless, since differences of 1 per cent. in the estimation of the copper content would, in general, in the making of mixtures, lead to little or no ultimate confusion. [These footnotes were contributed since the discussion took place.—ED.]

‡ *Proceedings of the Institution of Mechanical Engineers*, 1913, Parts 3–4, p. 869 *et seq.*

author) put forward had struck him forcibly when first coming into
contact with the actual facts in practice. Estimations were actually
made of the longitudinal and transverse hardness, and it was found
that it varied so slightly that it was not considered that strain hardening
was really the entire cause. That was the reason for putting forward
the suggestion contained in the paper. Mr. Murray had made some
interesting remarks on the question of the difficulty of believing what
was stated by workshop operators on what was hard and what was
soft to machine. In that connection an interesting case was brought
before his notice in the previous week. Considerable trouble had
been experienced with the steel supplied by a certain maker, the
statement being made that the same was very hard to machine. A
sample of the steel was forwarded to him for examination, and on
analysis it was found that the steel contained only 0·25 per cent. of
carbon, and was so soft that it was clogging the tool and thus stopping
the machine.

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COMMUNICATIONS.

Dr. CECIL H. DESCH (Glasgow) wrote that the following notes might
perhaps have some interest as bearing on the question of the machining
qualities and hardness of brass. Two specimens of 60 : 40 brass rod
were received, one of which (A) was reported to machine easily, whilst
the other (B) was stated to be hard to machine under the same condi-
tions. Both proved to have the same chemical composition. Micro-
scopical examination showed that A had the parallel structure charac-
teristic of a rolled rod, whilst B had the irregularly oriented α and β
structure found in castings or hot forgings. There was little difference
between the structures in transverse section.

A Brinell machine not being available at the time, a lever machine
was extemporized, using an 8 mm. steel ball and a load of 320 kg.
It was found that concordant results could be obtained with this
machine, but that the Brinell numbers obtained by its use were con-
sistently higher than those found in the normal method of testing.
For comparative purposes this did not affect the results. The brasses
A and B gave identical numbers when tested on a transverse section.
When longitudinal sections were tested, however, the softer metal, A,
gave a lower Brinell hardness than B in the ratio 100 : 116.

It was thought that a sclerometric test might give results more
closely in accordance with the machining qualities of the brass. The
sclerometer used was on the Martens principle, and was constructed in
the workshop of the Chemistry Department of Glasgow University. A

diamond point was carried on one end of a light pivoted arm, and the specimen of metal, of the size generally used for microscopical examination, was mounted on a travelling carriage, moving freely on ball bearings along a straight path. A traversing movement was also provided, so that several parallel scratches could be made on the same surface. A load of 50 grms. was applied to the diamond point. The surface of the specimens was polished in the usual way, and after testing the breadth of the scratches was measured under a microscope by means of a Ramsden eyepiece micrometer. Four scratches were made on each specimen, and the breadth of each scratch was measured in six places, the mean of the 24 readings being taken as a measure of the hardness.

Identical figures were obtained on transverse sections of the two brasses, but on longitudinal sections the hardness of A and B was found to differ in the ratio 100 : 115, the easily machined alloy being the softer. The closeness of the correspondence with the Brinell readings is doubtless accidental, but the results seem to show that sclerometric tests may be of value in determining the machining quality of brass.

In the present instance, microscopical examination suggested that the hardness of B was due to somewhat rapid cooling, the proportion of β being slightly greater than that in A.

Mr. F. JOHNSON, M.Sc. (Birmingham), in continuation of his remarks at the meeting, wrote that, as bearing out his (Mr. Johnson's) contention that data relating to castings should be plotted separately from those relating to stampings, he would quote the following results which had been obtained from the same bar of metal :

Condition.	Composition.		Yield Point. Tons per Sq. In.	Ultimate Stress. Tons per Sq. In.	Elongation.	Hardness.
Chill-cast bar . .	Copper	56·67	13·6	25·25	9	...
	Zinc	41·78				
	Lead	1·17				
Bar annealed . .	Tin	0·08				
20 mins. at 700° C. .	Iron	0·30	13·0	27·4	15·5	...
Hot stamping from	Manganese . . .	trace				
above . . .	Ditto		11·65	24·2	19	...

Mr. H. L. HEATHCOTE, M.Sc. (Coventry), wrote that the relation of the machining qualities of 60 : 40 brass to some of its other properties had received some attention at the Rudge-Whitworth Research Labora-

tory. Unfortunately, owing to the exigencies of war-work, it had not been possible to conduct a thoroughgoing and systematic inquiry ; but he had succeeded in making a number of observations on the materials in current use ; and those bearing on the machining qualities were set out in Tables I., II., and III.

By machining qualities was meant the facility or otherwise with which the metal was turned, drilled, reamered, tapped, thread-milled, and died. With the exception of one, all the samples in Tables I., II., and III. were stampings. The opinion of each operator as to the machining quality was asked, and the verdict of this jury was taken as the basis for classification. In each case the tests, &c., were done on the actual stamping to which this verdict refers.

The only test requiring any explanation was that called the " tool test number."

The action of a tool might be analyzed into :

1. Compression,
2. Shearing,
3. Bending,

all of which occurred near the tool point and face.

The " tool test " was an effort to approximate to this action. The test-piece measured $1 \cdot 125$ in. $\times$ 0·25 in. $\times$ 0·25 in. A tool with a rounded edge was then pressed into one face of this, making a transverse notch of a standard depth.

The notched test-piece was then held, and struck hammer-blows of equal intensity, the result of this being to add bending and shearing to the compression produced by notching the test-piece.

The number of blows required to break the test-piece was, if there be ignored the effort required to compress it during notching, a measure of the energy required to break it—and presumably of the energy required to remove a shaving by an actual tool.

The results of the tests made on three classes of stampings—respectively easy, medium hard, and hard to machine—showed that, within the range covered by the tests :

1. The Brinell hardness was substantially the same whatever the machining qualities and ranges from—

105 to 67 on " hard " stampings.
116 ,, 67 ,, " medium hard " stampings.
109 ,, 67 ,, " soft " stampings.

This quite confirmed Mr. Ellis' findings, but it did not reflect in any way upon the reliability of the opinions of the machine operators. To them a metal was hard if it consumed more of their energy, to us if it resisted pressure ; and both ways of gauging hardness were good so long as we did not confuse them.

One was reminded of the Chinese way of reckoning distance. To them it was much longer from the village to the top of the hill than from

the hilltop to the village. And indeed one might ask : If it *takes* longer, why not *be* longer ?

2. The tool test number was fairly consistently less for 60 : 40 brass that machined well than for brass that was difficult to machine.

3. There was no obvious relation between machining qualities and yield point, ultimate breaking strength and elongation per cent.

4. The percentage of lead was fairly consistently greater in brass that machined well than in brass that was difficult to machine.

5. There was no obvious relation between machining qualities and the percentage of copper and zinc.

6. There was no clear relation between the percentage of tin, iron, aluminium, manganese, and machining qualities. A small percentage of these tended to improve, and a large percentage to mar, the machining qualities.

The conclusion arrived at was that machining trouble, when traceable to the material, was in 99 cases out of 100 due to the absence of a sufficient proportion of lead. Mr. Ellis' own results pointed in the same direction. The highest points on the black curve (Figs. 5 and 6) p. 41, corresponding to greatest power required for machining, were on the samples that contained the least lead.

The importance of uniform and free machining qualities was only realized to the full when untrained workpeople, day in day out, and night in night out, had to produce under high-pressure conditions munitions within narrow dimension limits, and semi-skilled fitters and tool setters had to maintain the tools and machines in proper condition. Other conditions being the same, variation of machining qualities meant variation of dimensions produced. This was true when the tools were not blunted ; but a " hard " bar would soon upset one or more of the tools and produce work that the gauges would reject.

The proportion of scrap soon mounted up when, for instance, six operations on the same article each having a tolerance of 0·005 in. were done at the rate of 800 to 1000 articles per operator per day.

The following specification was suggested as combining with the requirements of the designer, the requirements of the manufacturer and user of material for 60 : 40 brass stampings.

Metal.	Specification. Given per Cent.	Specification. Preferred per Cent.
Copper	58–62	59
Zinc	36–40	39
Lead	1–2	1·5–2·0
Total, other ingredients .	Under 0·5	0·5–nil

Stampings of 60 : 40 Brass of Good Machining Quality.

Machinist's Report.	Brinell Hardness Number.	Tool Test Number.	Yield Point. Tons per Sq. In.	Tensile Strength. Tons per Sq. In.	Elongation per Cent.	Lead per Cent.	Copper per Cent.	Zinc per Cent.	Tin and Antimony per Cent.	Iron per Cent.	Aluminium per Cent.	Manganese per Cent.
Very good	80	**13·2**	9·39	23·60	53·3	**2·42**	59·91	37·74	nil	0·04	0·05	trace
Very good	69	**11·5**	10·11	22·64	47·8	**2·35**	59·63	37·99	nil	0·09	0·05	nil
Good	73	...	9·09	23·19	33·3	**2·30**	58·52	39·03	nil	0·04	...	...
O.K.	73	**13·5**	10·59	24·45	51·11	**2·18**	59·65	37·89	0·24	0·27	0·02	nil
O.K.	75	**11·0**	10·68	24·37	40·00	**2·16**	58·99	38·52	0·14	0·134	0·07	trace
Very good	92	**5·0**	10·07	25·65	26·4	**2·04**	59·44	37·34	0·69	0·47	0·31	0·06
Ideal	...	...	11·03	22·9	22·2	**1·82**	59·41	38·70	0·14	0·23	...	trace
Kind they like	67	**13·2**	10·56	23·71	48·88	**1·68**	60·90	37·29	trace	0·120	0·150	trace
O.K.	...	...	12·03	22·61	28·9	**1·64**	60·32	37·78	0·32	0·07	0·15	nil
O.K.	99	**16·5**	11·43	26·98	40·00	**1·63**	58·73	39·15	0·28	0·118	0·151	nil
Good	90	**3·7**	10·52	25·20	23·4	**1·61**	59·29	38·07	0·49	0·34	0·24	0·038
Satisfactory	81	**9·5**	10·16	23·95	26·66	**1·50**	59·14	39·01	nil	0·036	0·064	nil
Soft	103	**14·5**	10·93	26·70	33·33	**1·44**	56·77	41·22	0·212	0·053	0·236	trace
Satisfactory	89	**21·75**	10·19	24·77	45·55	**1·34**	58·86	39·15	0·099	0·076	0·188	nil
O.K.	81	**9·75**	10·92	22·03	27·8	**1·15**	61·19	37·30	trace	0·17	0·16	0·03
O.K.	109	**7·75**	11·68	26·70	23·33	**1·10**	57·20	41·19	trace	0·033	0·072	nil
Satisfactory	94	**10·5**	9·83	22·83	21·11	**1·08**	58·70	39·86	nil	...	...	...
O.K.	73	**11·5**	10·19	21·97	46·7	**1·08**	62·35	35·91	0·16	0·12	0·13	0·02
O.K.	78	**8·75**	10·09	22·68	26·7	**1·05**	61·82	36·27	0·23	0·13	0·11	0·02
O.K.	80	**14·0**	10·02	24·96	44·44	**1·04**	59·44	39·50	nil	0·052	0·09	trace
O.K.	...	...	8·876	21·08	35·55	**1·02**	62·64	36·28	trace	0·148	0·15	trace
O.K.	81	**17·0**	10·58	24·37	45·5	**0·59**	58·95	39·82	0·32	0·14	0·09	trace

Stampings of 60 : 40 Brass of Bad Machining Quality.

Machinist's Report.	Brinell Hardness Number.	Tool Test Number.	Yield Point. Tons per Sq. In.	Tensile Strength. Tons per Sq. In.	Elongation per Cent.	Lead per Cent.	Copper per Cent.	Zinc per Cent.	Tin and Antimony per Cent.	Iron per Cent.	Aluminium per Cent.	Manganese per Cent.
Does not drill well	80	**33·0**	9·09	25·48	56·6	**0·69**	59·86	38·81	...	0·10	...	...
Hard	75	**27·5**	9·21	23·94	52·2	**0·65**	61·30	38·12	trace	0·06	0·04	nil
Hard	92	**50·0**	10·74	26·83	40·00	**0·61**	62·04	37·40	0·19	0·10	0·05	0·03
Hard	69	**30·0**	9·53	22·46	53·33	**0·57**	62·03	37·10	nil	0·067	0·170	nil
Very hard	82	**20·0**	9·74	23·88	41·11	**0·56**	60·18	39·15	nil	0·05	0·045	very slight trace
Hard	78	**29·2**	11·32	24·58	54·4	**0·52**	61·28	38·04	0·24	0·07	0·12	trace
Hard	67	**34·0**	11·49	24·33	46·7	**0·46**	61·27	38·22	0·28	0·05	0·06	nil
Very hard	99	**32·0**	11·49	27·52	26·7	**0·43**	59·47	38·04	1·15	0·57	0·08	0·13
Hard	77	**21·0**	10·92	25·30	45·5	**0·42**	60·82	38·33	0·3	0·04	0·05	trace
Hard	(bar tested—not stamping)	...	24·19	34·30	28·8	**0·40**	59·20	38·51	0·89	1·09	nil	...
Hard	89	**28·0**	10·21	25·06	41·1	**0·33**	58·71	40·20	0·21	0·04	0·034	0·02
Very hard	...	...	...	...	...	**0·29**	60·71	38·18	nil	0·15	0·10	present
Very hard	...	...	9·99	21·13	21·1	**0·27**	61·64	37·94	trace	0·08	0·16	nil
Very hard	...	...	9·94	19·04	22·2	**0·22**	...	...	...	...	...	trace
Very hard	...	**55·0**	9·51	19·36	25·5	**0·17**	61·98	37·95	nil	0·08	0·07	trace
Hard	72	...	8·70	20·98	27·8	**0·10**	62·07	37·23	trace	0·06	0·19	nil
Hard	81	**31·25**	8·98	24·17	51·1	**trace**	60·33	39·50	0·04	0·04	0·17	nil
Hard	75	**53·0**	8·19	22·25	44·4	**trace**	61·20	38·50	nil	0·03	0·09	0·25
Very hard	105	**47·0**	10·15	22·92	37·8	**nil**	57·80	39·60	0·99	1·01	0·08	trace
Very hard	...	...	...	...	...	**nil**	58·09	41·30	0·57	0·005	...	

Stampings of 60 : 40 Brass of Indifferent Machining Quality.

Machinist's Report.	Brinell Hardness Number.	Tool Test Number.	Yield Point. Tons per Sq. In.	Tensile Strength. Tons per Sq. In.	Elongation per Cent.	Lead per Cent.	Copper per Cent.	Zinc per Cent.	Tin and Antimony per Cent.	Iron per Cent.	Aluminium per Cent.	Manganese per Cent.
Harder than usual	116	**6·5**	12·20	30·40	27·8	**1·03**	56·1	41·97	0·20	0·07	0·23	nil
Tough	under 67	**25·0**	10·11	22·95	54·4	**0·71**	61·74	37·27	nil	0·20	0·04	nil
On the hard side	67	**28·5**	8·32	22·27	56·7	**0·59**	61·26	37·99	nil	0·05	0·04	trace
Tough	81	**22·7**	11·20	25·27	52·2	**0·54**	60·68	38·52	0·31	0·06	0·07	nil
On the hard side	80	**19·0**	9·70	24·37	44·4	**0·52**	60·16	38·72	0·21	0·07	0·09	nil
Tough	72	**20·5**	8·76	22·72	55·5	**0·50**	61·49	37·74	nil	0·08	0·16	trace
On the hard side	80	**29·0**	9·60	25·26	48·9	**0·49**	60·94	37·94	0·35	0·13	0·02	trace
Rather hard	80	**23·0**	12·23	20·41	21·1	**0·46**	60·90	38·08	0·25	0·14	0·06	0·03
On the hard side	75	**23·0**	8·11	23·49	57·8	**0·40**	61·63	37·74	nil	0·09	0·18	nil

Mr. Arthur Stubbs (London) wrote that on p. 27 the author stated that, generally speaking, the casting temperature was of little importance in connection with the Brinell hardness and machining properties of stampings. In the first place, he would like to ask if the author could state the temperature at which the six castings referred to in Table A were cast ?

He hardly agreed that heating prior to stamping would result in eliminating variations due to casting temperature, as the rate of heating, and more especially the rate of cooling, undoubtedly affected the resulting Brinell hardness number. It was realized that cooling only took place after the stamping process was finished, but if it were desired to normalize the castings before stamping, this could only be done by heating and slow cooling, and afterwards heating a second time for stamping.

On p. 28 the author referred to the influence of variations in stamping temperatures, and he (Mr. Stubbs) would like to ask what were the maximum and minimum temperatures that the author would recommend for stamping ?

Did the author really consider that for the benefit of the product a low stamping temperature was more desirable ? If the evil effects of a high stamping temperature could be overcome by subsequent annealing, as they could within certain limits, was it possible entirely to remedy the effects of cold working—*i.e.* stamping at too low a temperature—by subsequent annealing ? In his (Mr. Stubbs') opinion it would appear safer to employ a high stamping temperature, and this was certainly what he had found in practice. One great trouble that he had experienced in stamping at a low temperature was that some of the stampings developed age cracks, *i.e.* after a certain time—say, from a few weeks to three or four months—the stampings would develop a crack or cracks, and these would increase in size until the stamping had apparently got rid of its internal stresses.

Doubtless this defect could be overcome to a certain extent by annealing after stamping, but the point he wished made clear was : would the effect of annealing have a greater and more beneficial effect in the case of hot-worked stampings, and would not the final product be more satisfactory ? He fully endorsed the author's remarks on p. 32 regarding the unreliability of machine operators upon the hardness or otherwise of stampings, but he would like to ask if the author had satisfied himself that the Brinell machine really revealed the difference of hardness as understood by the machinist ? He (Mr. Stubbs) had found that hardness often included toughness in cutting as against free cutting. That difference was, perhaps, more prominent in steel, where one might have two samples of the same hardness and yet the machining properties were entirely different.

With regard to the annealing temperature recommended by the author, he agreed that this should be preferably below 600° C. The length of time of annealing was an important factor, but provided the stamping were thoroughly soaked, *i.e.* was at an uniform tempera-

ture throughout, was any real commercial advantage to be obtained by long annealing ?   He realized, of course, that what was sometimes metallurgically desirable was not always commercially possible.

In the case of steel stampings no advantage seemed to be gained by long soaking after the stamping had reached the desired uniform temperature throughout, but rather the contrary, especially at temperatures below 600° C.

The conclusion arrived at by the author on p. 38, with regard to the Brinell hardness of the copper-zinc alloys in the range of 55 per cent. and 65 per cent. of copper, was a highly important one and would doubtless be made use of in works practice ;   but had the author any data available showing the difference that one would get in the hardness number in the case of rolled or extruded rod against a cast rod, both of the same chemical composition.   Further, had the author any information to show the difference obtained in Brinell hardness when using metal of the same analysis by—

(*a*) Stamping direct from a rolled or extruded bar,
(*b*) From a chilled cast bar,

and would the author state which of the three methods he considered the more desirable practice—*i.e.* stamping direct from a rolled or extruded bar, stamping direct from a chilled cast bar, or stamping from a chill casting ?

On p. 40 the author gave the size of the specimens used for tensile tests, and it would have been highly desirable, had it been possible, to have had the results stated using a larger-sized specimen.

In conclusion, he desired to add his tribute to the extreme value of the paper both from a scientific and a practical works aspect.

Mr. Ellis, in further reply to the discussion at the meeting, wrote that Fig. 4 included the mechanical test figures of both castings and stampings.   Mr. Johnson had suggested that these figures should be separated.   The author agreed that had the separation of stampings and castings not been subjected to thermal treatment, the results would have been justified.   Both the stampings and castings had, however, been annealed at 650° C., and were, in the author's opinion, thereby rendered almost identical in condition.   This opinion was supported by the following figures, which represented average test figures for certain of the castings and stampings in question :

No. of Casting or Stamping.	Copper per Cent.	Lead per Cent.	Iron, Aluminium, per Cent.	Yield Point.	Maximum Stress.	Elongation per Cent.
3	57·1	0·90	0·16	13·4	28·6	26·0
4	57·1	0·91	0·15	11·2	27·9	24·0
1ᴀ	57·2	0·73	0·34	12·8	30·3	27·5
2ᴀ	57·3	0·96	0·39	11·2	28·3	20·0

The copper content of the stampings (1A and 2A) differed only slightly from that of the castings (3 and 4), while the mechanical tests obtained could be termed almost identical.   Professor Turner had pointed out that the straight line relation was limited in its range.   This fact was worthy of emphasis, and the author, in the first paragraph on p. 27 of the paper, had endeavoured to make this important point clear.

The author, in reply to the written discussion, thanked Dr. Desch for his interesting note on the comparative hardness numbers of the two samples of rod.   The author noted that Dr. Desch found a considerable difference in the hardness numbers obtained in transverse and longitudinal sections of the rod that had apparently been rolled.   The author, as stated in his reply at the meeting, made similar tests, but found that the hardness numbers were very nearly identical.   Dr. Desch's findings in this connection were worthy of note, since (though this matter required closer investigation) they tended to confirm the author's suggestion that stability of arrangement played a part in the hardness of the material in question.

Mr. Heathcote's remarks were of very great interest.

The author was surprised to note that stampings having a Brinell hardness number as high as 109 were termed of good machining quality, as he had found that, almost without exception, when a stamping had had a Brinell hardness number upwards of 80, it had been termed hard to machine, hence he suggested that it was better to err on the side of a high rather than a low copper content.   It was possible that the stampings referred to in Mr. Heathcote's remarks were of varying origin —some from castings, some from rod.   This, it was considered, would account for the differences in the hardness of easily machined stampings.

The presence of lead had long been known to effect a considerable improvement in the machining properties of brass, particularly as far as the free-cutting properties of the same were concerned.   In certain war stores, however, the amount of lead allowable was limited, and the experiments detailed in this paper referred, almost without exception, to stampings containing less than 1 per cent. of lead.   The exceptions were contained entirely in Table F.   The author could not agree that Mr. Heathcote's remarks with regard to the highest points on the black curve (Figs. 5 and 6), p. 41, were conclusive.   The author was, however, diffident in making a statement in this connection, as this subject required further investigation before definite conclusions could be reached.   Mr. Heathcote's remarks in his concluding three paragraphs were of great importance, and, when considered in conjunction with those of Mr. E. L. Robinson at the meeting, indicated the necessity of attaining uniformity of material in the workshop.

The author thanked Mr. Stubbs for his kind remarks, but regretted that he was unable to quote the temperatures at which the castings, referred to in Table A, were poured.   He would, however, point out that the very slight differences in composition of these castings could not account for the noticeable differences in Brinell hardness numbers.   On

the other hand, the comparative uniformity in the last factor that had been induced by annealing subsequent to casting appeared to indicate that differences in hardness, such as were due to casting temperature, were almost entirely eliminated by the heating necessary prior to stamping. The most desirable condition for stamping was that the alloy should be constituted of practically pure β, hence there did not appear to be any necessity for a " normalizing " process.

The following statements defined the condition more clearly :

1. The minimum stamping temperature for those brasses which contained between 59 and 61 per cent. of copper was represented by the transition point $\beta - a + \beta$.

2. The maximum stamping temperature should not be less than 20° C. below the temperature represented by the " solidus " of the alloy in question.

3. The stamping of the alloys in the above range at temperatures below the $\beta + a + \beta$ transition point was liable to result in " season cracking," not, it was thought, on account of cold-work, but because of the arrest of the $\beta - a + \beta$ transition. Since the season-cracking of cold-worked 60 : 40 rod could be prevented by annealing at temperatures between 200° C. and 300° C. for a short period, the forging of brass at temperatures such as allowed of the stampings being removed from the die at temperatures above 300° C., as generally occurred, was unlikely to be the cause of failure that could be attributed to cold-work.

With regard to clause (1) above, if account were taken of the deleterious effect of heating 60 : 40 brass for prolonged periods at temperatures between 750° C. and 800° C., one was left with the range of temperature 800° C. to 850° C. as that most suited for the purposes of stamping. But, as stated on p. 32 of the paper, it was not considered that within the short period usually accorded to the heating of the castings prior to stamping much evil would be effected by retaining the same at temperatures between 750° C. and 800° C. Hence it was considered that the range 750° C. to 800° C. could be termed " suitable." The higher the temperature of the casting prior to stamping, the harder the finished stamping was likely to be within this range.

That the Brinell test did not distinguish between the varieties of hardness, as understood by the machinist, was made evident if a comparison were made of Figs. 1, 5, and 6.

The author had no data as to the relative hardness of stampings made from bar, rod, and castings. Neither could he give a definite opinion as to the relative merits of the practices noted by Mr. Stubbs.

SURFACE TENSION AND COHESION IN METALS AND ALLOYS.*

By SYDNEY W. SMITH, D.Sc., A.R.S.M.

THE work recorded in a previous communication † was mainly directed towards the development of a method by which the surface tensions of molten metals, differing widely in their general properties, may be compared under similar conditions.

The stages were described by which progress has been made, based upon the observation that capillary depressions are obtainable in the surfaces of molten metals when carbon tubes of fine bore are plunged vertically into them. The results, obtained from a number of pure metals by measuring these depressions and calculating from them the corresponding surface tensions, were given.

These results were discussed, and certain conclusions and their significance were indicated.

Of these conclusions two relate to pure metals in the molten state.

Firstly.—That, in accordance with other properties of the elements, the surface tensions of molten metals are periodic functions of their atomic weights.

Secondly.—That these surface tensions appear to vary inversely as some function of the atomic volumes.

A third conclusion was given by way of briefly indicating the bearing which the determinations on pure metals appear to have on the much wider questions of the condition of metals when alloyed, *i.e.* on the properties and constitution of alloys generally. Attention was drawn to the fact that the greatest effect, produced by the addition of small proportions of other metals to pure gold in disturbing and diminishing its cohesion, is seen when those

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impurities are the metals in its own period which have similar atomic weights, but much larger atomic volumes and lower surface tensions.

The question of the constitution of alloys is, of course, more attractive and offers wider fields of usefulness than a consideration of the pure metals themselves, which, as such, are rarely employed. It is thought, however, that the wider question cannot be approached from the point of view of surface tension and its significance until a full consideration has been given to the relation which this property bears to other determined constants of pure metals.

The ultimate aim, however, is to utilize the method which has been developed in order to provide another means of approaching questions involved in the constitution of alloys by affording evidence of molecular influences which are operative before solidification occurs. In this way it is hoped that information may be gained regarding varying surface tensions which will supplement the methods of pyrometric measurements of thermal changes and the methods of metallographic analysis, which together have furnished the greater part of the knowledge acquired during the past twenty years in relation to these matters.

It is proposed to indicate briefly the directions in which work will be continued when opportunity arises and to outline the character and significance of the results which may be expected.

Surface Tension as an Index of Cohesion in Pure Metals.

The particular property which is dependent on the molecular conditions of metals, and regarding which it is hoped to obtain quantitative information, is that of cohesion, in virtue of which metals and alloys display those attributes of strength and ductility upon which their use depends. Hitherto, this property has only been studied empirically by various forms of mechanical tests, supplemented in recent years by a considerable amount of research which has been directed towards observing

and explaining, by the methods of metallographic analysis, the changes which occur at the interfaces of contiguous crystals and in the crystals or crystal grains themselves, under the influence of " strain " or of " heat treatment."   These effects, produced by " cold work " and by " annealing," have led to a theory of " hard " and " soft " states in metals involving the existence of an " amorphous phase " in strained material, considerations which have formed the subject of notable researches by Beilby, Rosenhain, and others.

The conceptions of atomic and molecular constitution as developed in recent years by Thomson, Rutherford, Böhr, and Moseley must receive careful consideration in regard to metals and alloys, while the work of Barlow and Pope, and that of Bragg especially, are clearly of extreme importance.   Dealing as they do, however, entirely with conditions which involve crystallization, the latter must be pursued on independent lines from those at present suggested.

It is hoped now to approach this question of cohesion by means of the surface tensions in the molten state, as being the only evidence so far available of molecular influences which are operative before the forces determining crystallization manifest themselves.

The work of Van der Waals and others on the continuity of properties in the liquid and solid states should enable us to assume that relative differences of surface tension in the molten state will have their counterparts in relative differences of cohesion in the solid state.

It will be shown that in many important respects this is actually the case.

It may be mentioned in passing that the values obtained in the course of this work for the surface tensions of pure metals have recently been utilized by F. C. Thompson,* with certain assumptions of continuity of properties, in developing a theory of the behaviour of pure metals below the elastic limit in order to give an interpretation of the real significance of the elastic limit itself.   By extrapolating values for the interfacial tensions at the boundaries of crystals, which make up a mass of metal, from the

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* *Transactions of the Faraday Society*, 1915, vol. xi. Part I.   *Journal of the Iron and Steel Institute*, 1916, Part I.

values given for liquid surface tensions, he has indicated an hypothesis which appears to accord with the facts as determined by mechanical tests.

In approaching this question of cohesion, either in the liquid or in the solid state, considerable attention has been given to the conception of " internal cohesion " or " intrinsic pressure " which forms an essential part of the basal idea in the Laplace theory of capillarity, and which has been adopted and developed by Rayleigh, Worthington, Osborne Reynolds, Berthelot, Traube, and others. This conception of " intrinsic pressure " is regarded as being a measure of the cohesive force by which the molecules or particles of a substance, liquid or solid, are held together, that is, the force which must be applied to cause separation in liquids or fracture in solids, or briefly, their tensile strength.

As regards liquids, actual measurements of intrinsic pressure have been made for a number of liquids by experimental methods developed by Berthelot,* Worthington, and Osborne Reynolds, but the experimental difficulties of effecting these measurements with molten metals appear at present to be too great. By the application, however, of Van der Waals' equation to liquids, it has been shown that the factor $\dfrac{a}{v^2}$ is a measure of the intrinsic pressure. The value of this pressure has been calculated for a number of liquids.

It is then seen that a high surface tension is always accompanied by a high intrinsic pressure, so that through surface tensions we have a means of approaching relative intrinsic pressures. Although these two physical constants are involved as factors in the Laplace formula for capillarity they have not been regarded as related by any simple expression. Walden,† however, has given a number of empirical relations for liquids, but their applicability to metals does not appear possible until further knowledge of certain physical constants is available. His views on the intrinsic pressures of liquids as affecting their mutual solubilities will be referred to later (p. 82).

Of those physical constants of liquids which have so far been

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* Poynting's " Properties of Matter," p. 123.
† " Surface Tension and Surface Energy," Willows and Hatschek, p. 27.

definitely related to surface tension, the following may be mentioned :

> Molecular Volume.
> Compressibility.
> Coefficient of Thermal Expansion.
> Vapour Pressure.
> Solubility.

In passing from a consideration of the surface tensions of liquids to the intrinsic pressures of solids, it will be shown that the above list has been extended by Traube to include certain other properties.

In 1903, Traube * proposed a consideration of the physical properties of the elements from the point of view of Van der Waals' equation of condition :

$$(p + \frac{a}{v^2})(v - b) = \text{RT}.$$

He had previously shown that the equation is applicable to highly compressed gases and, later, to homogeneous liquids, if their volumes are regarded as being made up of two complements, viz. :

(1) Their " proper " volumes.

(2) Their co-volumes (the intra-molecular spaces). These two quantities, as calculated by Kopp's method, proved to correspond with the quantities b and $(v - b)$ of Van der Waals' equation.

He proceeded, therefore, to extend the application of the equation to the solid state in order to consider the physical properties of the elements.

Metals were chosen, in the first instance, on account of the simple and probably monatomic character of their molecules even in the solid state.

He calculated the constants a and b for a certain number of metals by introducing into the equation,

$$(p + \frac{a}{v^2})(v - b) = \text{RT},$$

the values of the volumes at two temperatures near 0° C. The volumes selected were respectively :

(1) $v = \frac{A}{d}$ (at temperature t),

> where A = atomic weight,
> d = density.

(2) v calculated from the coefficients of cubical expansion 3β, using Fizeau's values.

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* Abstract, *Journal of the Chemical Society*, 1903, ii. p. 355.   *Zeitschrift für anorganische Chemie*, 1903, vol. xxxiv. (4), pp. 413–427.

In this way he obtained values for the internal pressures $\left(\dfrac{a}{v^2}\right)$ which he found to be very large and for the co-volumes $(v - b)$ which are small.

Richards * had previously arrived at values for the internal pressures of a number of metals by considering the work done on them by the application of heat. Assuming that the heat supplied to a metal is entirely expended in overcoming the internal pressure he equated these two quantities :

$$P = C\,\frac{dt}{dv},$$

where

C = molecular heat capacity,
v = volume,
t = temperature.

The values for internal pressures obtained by Traube as the result of his application of Van der Waals' equation were, however, only one-third of those obtained by Richards. On the supposition that the constant R has the same value for metallic atoms both in the solid and gaseous state, he concluded that only one-third of the energy supplied to a metal as heat is expended in overcoming the internal pressure, the remainder going to increase the kinetic energy of the molecules.

From this conclusion he showed that the coefficient of expansion of the co-volume of a metal is a constant and equal to $\frac{1}{273}$, and that consequently the internal pressures vary very little with temperature.

He found this relation to be true for monatomic metals and multi-atomic metalloids, but not for the halogens.

It may be of significance in this connection that the experimental determinations of the surface tensions of molten metals showed but very little variation over considerable ranges of temperature.

The values for the internal pressures of certain metals in the solid state given by Traube are tabulated below, with the values for the surface tensions in the molten state obtained in the course

of this work. They have also been plotted in the accompanying curve (Fig. 1).

Metal.	Surface Tension (dynes per cm.).	Internal Pressures (megabars, or 10^6 dynes per sq. cm.).
Antimony . . .	274	...
Bismuth . . .	346	...
Lead	424	51,500
Tin	480	68,700
Aluminium . . .	520	119,300
Zinc	707	108,900
Silver	858	161,900
Gold	1018	178,500
Copper . . .	1178	236,100
Iron	...	239,000
Nickel . . .	...	306,300

The relation indicated by the plotted values may be expressed by the equation :

$$\text{Surface tension} = (\text{Int. press.} \times 10^{-2}) \times 0\cdot437 + 200.$$

By extrapolation, figures may therefore be given for the cases in which blank spaces appear in the above table.

Thus, Surface tensions $\begin{cases} \text{Fe} = 1244 \\ \text{Ni} = 1538 \end{cases}$

Internal pressures $\begin{cases} \text{Sb} = 16,933 \\ \text{Bi} = 33,412 \end{cases}$
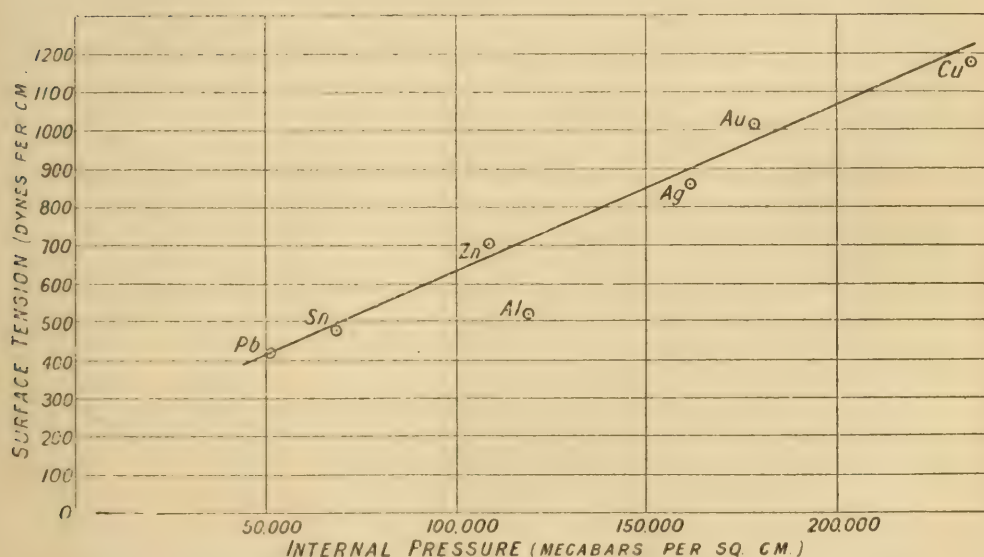
Fig. 1.—Surface Tension and Internal Pressure.

Compressibility, Surface Tension, and Cohesion.

Worthington's experiments, besides giving the tensile strength of certain liquids, established the very important fact that " the force required to increase the volume of a given body of liquid by a certain amount is the same as that required to decrease it by the same amount," *i.e.* to compress it. This clearly means that the greater the pressure required to compress a given liquid, or, in other words, the smaller its compressibility the greater will be its intrinsic pressure.

The parallelism which is thus indicated is found to exist between the intrinsic pressures of a number of liquids and their compressibilities.

It has also been shown that the surface tensions of certain liquids follow very closely their compressibilities.

Richards and Matthews * concluded from their examination of 37 organic liquids that the surface tensions and compressibilities are related by the expression :

$$\gamma . \beta^{\frac{4}{3}} = \text{constant,}$$

where

γ = surface tension,
β = compressibility of unit volume per atmosphere pressure.

A closer proportionality of β and γ has been shown by Röntgen and Schneider, by considering β as the change in volume of an equal number of molecules instead of that of unit volume.

The fact that substances of high surface tension are only slightly compressible is discussed by Richards and Matthews from the point of view of the theory that the atoms are compressible, and they contend that compressibility must depend not only on the volume changes resulting from the varying molecular distances, but also on the internal changes of the molecules themselves.

The interest which attaches to this view that a relation exists between the intrinsic pressures and the compressibilities of metals is that it appears to open a way for approaching those funda-

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* *Journal of the Chemical Society,* 1908. ii. p. 158.　*Zeitschrift für physikalische Chemie,* 1908, vol. lxi. p. 449.

mental aspects of cohesion which are collectively referred to as "hardness."

The importance of a knowledge of the relative compressibilities of the elements was recognized by T. W. Richards. His results were utilized by Traube in order to develop a relation between atomic or molecular compressibilities and the intrinsic pressures which he had arrived at by the application of Van der Waals' equation to the solid state.

Certain of the stages will be briefly indicated by which the work of Richards and that of Traube have furnished information of the greatest importance in regard to problems which form the subject of the present inquiry.

The work of Holmes and Sageman has also a very important bearing on this question and is, in many ways, analogous to that of Richards, but will be discussed more appropriately in dealing with alloys regarded as solutions.

The Work of T. W. Richards.—In 1901, Richards * and his collaborators commenced a series of experiments in relation to compressibilities and volume changes of liquids, followed later by those of solids.

It was pointed out that great compression of a substance may be due to two causes :

(1) One applied from outside.

(2) Another due to mutual internal attraction or affinity of the smallest particles for each other.

The small compressibility of liquids and solids was taken as evidence of a great compression of the second kind, and it was hoped, therefore, that a study of volume changes might lead to some knowledge of the affinities at work.

These were examined from two points of view, which have been subsequently developed on independent lines and with great care by Holmes and Sageman :

(1) That of changes of volume which occur when liquids are mixed, but do not re-act with each other (these have been distinguished by Holmes and Sageman as "physical changes ").

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(2) That of changes of volume resulting from chemical affinity or combination.

Richards concluded that the atomic hypothesis must be modified, so that the " compressible environments," or " atomic shells " around the centres of gravity and affinity, are not so entirely disregarded as usual.

Briefly, he regarded atoms themselves as elastic and compressible, and in 1904 * he brought forward further evidence as to the significance of changing atomic volumes to support the theory. Varying intensities of internal or cohesion pressure were regarded as capable of explaining the variety of physical properties, special mention being made of tenacity and malleability.

In 1907,† the compressibilities of 35 elements having been determined with great care, he was able to show that " *compressibility is a periodic property of the elements*, and that it is probably, in part, associated with the same causes which determine atomic volume and volatility." The periodicity which has been shown to exist between the surface tensions of metals brings this property into relation with compressibility.

In his Faraday Lecture,‡ Richards summed up his conclusions in the statement that " the bulk of evidence strongly indicates that *cohesiveness as well as chemical affinity exerts pressure in its action*, and hence that each plays a part in determining the volumes occupied by molecules."

In metals and alloys, where evidence of chemical affinity is less frequent than that of their surprising cohesiveness, the latter is seen to call for the greater consideration.

The Work of I. Traube.—In 1904 Traube discussed the properties of substances regarded as functions of the space occupied by their atoms and molecules, and proposed a systematic classification of the elements based on this point of view. He claimed that the physical and chemical properties of elements and compounds depend primarily on the space occupied by their atoms and molecules, and that this factor has a much greater influence on their general properties than atomic weight. This is a view which

must commend itself very strongly to those familiar with the
behaviour of metals when alloyed with others having different
atomic volumes. Reference has already been made to this aspect
of metallurgical experience (p. 65).

It is practically the view urged by Osmond and Roberts-
Austen and supported by Mendeléeff with regard to the properties
of pure metals to which small quantities of impurities have
been added.

A further conclusion was reached by Traube at this time.
He showed from his consideration of the factors $\dfrac{a}{v^2}$, and $(v-b)$
in Van der Waals' equation, that while thermal expansion is
almost entirely confined to the intra-molecular spaces, on the
other hand, from the fact that the constant b is very much
reduced by compression, he concluded that compressibility
affects the actual or "proper" volumes of the molecules them-
selves.

This conclusion he carried still further in 1909 * by establishing
a relation between the internal pressures of metals and their
atomic or molecular compressibilities.

Using the data for compression-coefficients of unit volume
obtained by Richards and his collaborators, in order to arrive
at *atomic* or *molecular* compressibilities, he found that the products
of the square roots of these quantities and their corresponding
internal pressures are very nearly constant for 14 metals in the
solid state.

$$\sqrt{\text{atom. compress.}} \times \text{int. press.} = C.$$

A point of great interest to metallurgists, to which reference
will be made later on, is that for iron he found high values,
which he attributed to the great influence exerted by small
traces of foreign substances on the internal pressure of this
element.

Surface tension is thus brought into association with com-
pressibility, both on account of its periodicity and also on account
of its intimate relation to internal pressure.

SURFACE TENSION AND HARDNESS.

In considering compressibility in relation to internal pressure and surface tension, reference has been made (p. 72) to the possibility that these relations may afford some clue to the factors which determine the attribute of cohesion which is spoken of in general terms as " hardness."

This quality of " hardness " has long been recognized as something other than a specific property of metals * and as depending, like " strength," on the conditions under which it is measured.

It is abundantly evident, however, that it is intimately connected with cohesion. Methods which aim at comparing relative cohesions should afford, therefore, some evidence of relative hardnesses. These relative hardnesses, as measured at present, are merely empirical determinations made in different ways and on different scales, for use as criteria in industrial work.

Traube † found a parallelism between his " internal pressures " and the hardnesses of a certain number of metals, but the parallelism so found was not, as he pointed out, so striking as that with the corresponding moduli of elasticity.

Relative surface tensions in the molten state, as measures of cohesion, may, therefore, show some relation to hardness in the solid state.

An increase of hardness which is known to result from the formation of a solid solution by the addition of one metal to another, apart altogether from effects produced by mechanical work, is clearly of the nature of an atomic or molecular "rapprochement." Some further observations on this aspect of hardness are offered in dealing with solid solutions (p. 94).

The consideration of relationships between internal pressure and atomic or molecular compressibility clearly leads to a conception of the mechanism of the changes produced by cold work. It is generally agreed that in order to give increased hardness the extent of the mechanical treatment must be such that it produces *permanent deformation*. It is difficult to conceive of this change being unaccompanied by volume changes resulting

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* Report of the Hardness Tests Research Committee, *Institution of Mechanical Engineers*, Nov. 1916.

† *Zeitschrift für anorganische Chemie*, 1903, vol. xxxiv. (4), pp. 413-427.

from atomic or molecular compression. The order of magnitude of the forces producing deformation is comparable with the pressure attributed to the internal molecular pressure as considered by Traube. This means that the factor p in Van der Waals' equation,

$$\left(p + \frac{a}{v^2} \right) (v - b) = \mathrm{RT},$$

instead of being that of atmospheric pressure, and therefore negligible under ordinary conditions, now becomes one of considerable magnitude, which must be added to the internal pressure. Since the equation of Van der Waals involves the assumption that the cohesive forces between the molecules vary inversely as the fourth power of their distances apart, it is not difficult to understand why a small compression should lead to a relatively great increase of internal pressure.

This conclusion indicates, therefore, that the effects of cold work in producing a relatively small increase in density will involve a correspondingly great increase of internal pressure, and of those attributes dependent on it. The investigation of volume changes in cold-worked material should therefore be approached with a full appreciation of the magnitude of the effect resulting from small changes. The investigation of such changes have convinced the author that useful and conclusive information in this direction can only be obtained by determinations made on comparatively large specimens. The crucial point to be considered in choosing the size of the specimen is the actual *change* in the volume of water displaced under the two conditions which are being compared.

The effects, both of softening and of recrystallization, which result from annealing, are capable of a reasonable interpretation on the grounds that they have their origin in the release of molecular compression. The molecular activity, which is initiated by a rise of temperature, restores the elasticity to the strained molecules held in compression and frees them to orientate themselves. The very fact of their closer juxtaposition under compression establishes the ideal condition for rapid " dressing " into alignment to form crystal grains.

TABLE OF RELATIONSHIPS.

Metal.	Surface Tension (fluid) Dynes per Cm.	Internal Pressure (solid). Megabars.*	Compressibility.		$\sqrt{\text{At. Comp.} \times \text{Int. Press.} \times 10^{-1}}$ = constant.‡	Atomic Concentration.		Hardness.	
			Per Unit Volume per Megabar $\times 10^{-6}$.†	Per Atomic Volume per Megabar $\times 10^{-8}$.		$\dfrac{\text{Fluid. Density}}{\text{At. wt.}}$	$\dfrac{\text{Solid. Sp. gr.}}{\text{At. wt.}}$	Bottone's Figures.§	Turner's Figures.‖
Antimony	274	...	2·2	...	...	0·0536	0·0558	...	...
Bismuth	346	...	2·8	...	...	0·0470	0·0470	...	...
Lead	424	51,500	2·2	40·04	3·26	0·0507	0·0550	0·0570	1·0
Mercury	447	...	...	...	...	0·0675	...	...	...
Tin	480	68,700	1·6	25·92	3·49	0·0560	0·0619	0·0651	2·5
Aluminium	520	119,300	1·3	13·13	4·32	0·0866	0·0821	0·0821	...
Zinc	707	108,900	1·5	13·70	4·03	0·0888	0·1077	0·1077	6·0
Silver	858	161,900	0·84	8·65	4·76	0·0875	0·0963	0·0990	...
Gold	1018	178,500	0·47	4·79	3·91	0·0932	0·0979	0·0979	...
Copper	1178	236,100	0·54	3·83	4·62	0·1308	0·1364	0·1360	8·0
Iron	...	239,000	0·40	2·84	(5·46)	...	0·1375	0·1375	15·0
Nickel	...	306,300	0·27	1·74	4·28	...	0·1408	0·1410	...

* Traube, *Berichte der deutsche physikalische Gesellschaft*, 1909, pp. 231–236.
† Richards, *Carnegie Institute Publications*, 1907, No. 76.
‡ Traube, *ibid.*
§ Bottone, *Chemical News*, 1873, p. 215.
‖ Turner, *Journal of the Iron and Steel Institute*, 1909, No. I. p. 434.

Surface Tension in Relation to Alloys.

In the foregoing sections the consideration of surface tension in relation to other properties has been confined exclusively to pure metals. Some observations will now be made with a view to indicating in what way a knowledge of surface tensions appears likely to lead to a better understanding of the molecular relations of metals when alloyed. A brief consideration will also be given to some recent work on the theory of solution in so far as its application would appear to assist in the same direction.

The insufficiency of mechanical tests was recognized long ago, and during the past twenty years the greater part of the increased knowledge of the constitution of alloys has been furnished by extensive researches in which the pyrometer has revealed molecular changes and the corresponding structural changes have been examined by the microscope. Pyrometry and metallography have thus together provided invaluable information to the user of alloys ; at the same time, however, they have widened the outlook and made evident other problems concerning which they are unable to give much enlightenment.

If we are to study the atomic or molecular constitution of an alloy in relation to those properties which depend on cohesion, we must clearly have some means of determining the degree to which the cohesion of the molecules is disturbed by the addition of one metal to another. Reference has already been made to the efforts by which Roberts-Austen sought to establish a relation between the tensile strength and elongation of gold containing small quantities of impurities and the atomic volumes of those impurities. He was careful to point out, however, that inconsistencies must be expected from this method of attack, as such determinations must be subject to factors which are not the direct result of the added metal.

It does appear, however, that in measurements of surface tensions of molten alloys we have a means of approaching the problem under conditions which are free from the factors which confuse the evidence under solid conditions.

In doing this it is thought that the view of " atomic percentages " rather than " weight percentages " should be kept more clearly in mind than is usually the case in work on alloys. The

consideration of " atomic percentages " has been, of course, by no means entirely neglected.

Alloys and Solutions.

The investigation of alloys has, for many years, been approached from the point of view which regards them as being analogous to solutions or to partially miscible liquids.

The effect, therefore, of the addition of one metal to another, regarded respectively as the solute and the solvent, in raising or lowering the surface tension of the solvent, should furnish data which, having regard to the continuity of properties in the liquid and solid state, should enable these changes to be correlated to the evidence afforded by mechanical tests.

In this way it is hoped to utilize the measurable capillary effects produced in fine carbon tubes by the surfaces of molten alloys, in order to study the changes in molecular cohesion when elements of certain atomic weight and atomic volume are added in atomic percentages to pure molten metals of other atomic weights and atomic volumes.

In approaching this question, therefore, it is clearly of importance to give consideration to views which have been put forward from time to time as to theories of solution in so far as such a wide question may be limited to the case of mixed metals. In dealing with aqueous solutions a distinction runs through nearly all work as between dilute solutions and concentrated solutions. To some extent this distinction holds for alloys, although it will be necessary to consider both cases.

Richards, Holmes and Sageman, Traube and others have shown the inadequacy of existing theories of solution, although the benefits conferred by these theories are, of course, beyond all question.

With regard, for instance, to Van't Hoff's laws for dilute solutions, Traube objects to too close an analogy being drawn between gases and dilute solutions. These analogies present even greater difficulties in the case of alloys. He claimed that an acceptable theory of solution must account for the part played by the solvent. This is a view which must commend itself to metallurgists whose constant care is the effect which the " solute " is likely to have on the behaviour of the " solvent."

Traube's work was primarily directed towards developing a theory of solution which would explain osmosis, but in this direction his efforts appear to have been adversely criticized. This may have led to the comparative neglect of those portions of his work which appear to furnish suggestions in seeking to establish relations between the surface tensions of molten alloys and their properties in the solid state.

The well-known objections to current theories of solution owing to their failure to interpret the case of strong solutions, and to the discrepancies shown by non-aqueous solutions, led him to emphasize the importance of the " intensity factor " as distinct from the " capacity factor," which he regards as being the only one considered in modern theories of solution, in so far as they are invoked to explain osmotic pressure and electrolytic dissociation. This intensity factor he calls the " cohesion pressure," which he regards as the force with which a solute is retained in solution.

Although hitherto neglected, he regarded its examination in solutions as being as necessary as that of potential in electro-chemistry. The relation of this " cohesion pressure " to the " intrinsic pressures," already considered in dealing with pure metals, will be shown to be of great significance in considering certain properties of alloys. He pointed out that Gibbs had shown, thermo-dynamically, that a solute which diminishes the surface tension of a solvent tends to accumulate on the surface, and *vice versa*. He then proceeded to enunciate this principle in another form, thus : " The more a solute diminishes or increases the surface tension of a solvent, so much the smaller or the greater is its cohesion pressure (or solution tenacity), and that accord-ingly *the difference between the surface tensions of a solvent and a solution is a measure of the cohesion pressure of the solution.*"

This cohesion pressure, or the intensity factor, in his theory of solution, represents the force with which a solute is retained in solution, and in the following remarks it will be made the basis of the outlook on the cohesion of alloys when approached through a consideration of their surface tensions or intrinsic pressures and those of their constituents.

By measuring the surface tensions of salt solutions, Traube was able to arrange ions in the order of their cohesion pressures.

If it should be found possible to establish some analogous relations for molten metals and alloys, and to supply evidence for extending these relations to the solid state, a key would be found to a mass of empirical data which has been accumulated in the course of testing alloys for industrial purposes.

Traube's observations with regard to surface tension are carried a step further by Walden,* to whose empirical relations reference has already been made (p. 68).   By comparing the intrinsic pressures of various liquids and their solubilities in water, he found a parallelism between the two properties.   He found also that *the mutual solubility of two liquids is the greater the smaller the difference between their intrinsic pressures ;* if this difference is very great the liquids are practically immiscible.

With these conclusions of Traube and Walden before us, and the values given by Traube for intrinsic pressures in the solid state, and those for the surface tensions obtained in the course of this work, we have the means at hand of applying these views to some of the known facts regarding metallic alloys.

If we consider two extreme cases of mixtures of two metals, such as gold and silver on the one hand, and lead and zinc on the other, we know that the former are miscible in all proportions ; while the latter, although miscible at high temperatures, separate into two layers before solidification.

In the former case, the respective values for the intrinsic pressures given by Traube are—gold, 178,500 megabars, and silver, 161,900 megabars, figures which, relatively to the corresponding figures for other metals, are not very different from each other.   In the case of lead and zinc, however, the relative intrinsic pressures are very different, that of lead being 51,500 megabars, while that of zinc is 108,900 megabars, or roughly twice that of lead.

Thus, while in the case of gold and silver, which are completely miscible, the ratio is 52 : 48, the corresponding ratio in the case of zinc and lead is 68 : 32.   These facts are therefore in accord with Walden's generalization.

It should be observed also that while the atomic volumes of gold and silver are nearly equal, the ratio of those of zinc and

* *Journal of the Chemical Society,* 1909, ii. pp. 119 and 547. *Zeitschrift für physikalische Chemie,* 1909, vol. lxvi. pp. 385–444.

lead (9·15 : 18·20) is almost exactly the inverse of the ratio of their intrinsic pressures.

A similar comparison of the surface tensions of these two pairs of metals from the values found by the author shows ratios of 54 : 46 and of 62 : 38 respectively, figures which are in sufficient agreement with those given by the intrinsic pressures to suggest that conclusions drawn from surface-tension determinations may be comparable with those drawn from intrinsic pressures, since we have already seen (p. 71) that, although related apparently by a linear function, they are not directly proportional to one another. This application will be further developed in relation to certain properties of solid solutions.

Solid Solutions, Surface Tension, and Cohesion.

Alloys which are the results of their constituents forming solid solutions may be again divided into two classes, according as the constituents are :

(*a*) Solid solutions in all proportions.

(*b*) Solid solutions only in certain limited proportions.

In his concluding remarks to the Fourth Report of the Alloys Research Committee,* Roberts-Austen said :

" As regards the immediate future, I am of opinion that the nature of what may be called ' solid solutions ' of metals must be more carefully studied than has hitherto been the case. When this has been done, it will be desirable to continue the investigations of the influence of the atomic volume of elements, within the elastic limit and beyond it."

Subsequent work has tended to show more and more clearly the great importance relatively to all other types of alloys of those alloys which form " solid solutions." This importance has been generally recognized, and much work has been devoted to them. Their properties are similar to those of pure metals in being relatively soft, malleable, and ductile, and it was pointed out by Law † that practically all the industrial alloys which are capable of being cold-rolled, drawn, and spun consist of a single solid solution. As examples, he quoted brass, bronze (containing

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* *Proceedings of the Institution of Mechanical Engineers*, 1897, pp. 31–68.
† " Alloys and their Industrial Applications," 1909 edition.

less than 8 per cent. of tin), malleable phosphor-bronze, coinage bronze, aluminium-bronze (containing less than 7·5 per cent. of aluminium), cupro-manganese, cupro-nickel, nickel-silver (so-called German silver), standard gold, magnalium, and some of the nickel and manganese steels. Alloys consisting of two solid solutions are less ductile, but are still capable of being rolled and worked hot.

As instances of these he gave Muntz metal, manganese bronze, delta metal, and a number of other " special bronzes " and brasses.

It is therefore to a better understanding of the molecular relations of the constituents of these solid solutions that the application of the study of surface tension will be chiefly directed.

It is proposed to consider briefly certain of these alloys and their properties in relation to the surface tensions and intrinsic pressures of their constituents. Until actual determinations of their surface tensions have been made, it will only be possible to consider them in regard to their behaviour as determined by work in other directions.

Intermiscibility, Surface Tension, and Atomic or Molecular Volumes.

It has been said (p. 65) that the surface tensions of molten metals appear to vary inversely as some function of their atomic volumes. The significance of this observation in relation to cohesion lies in the fact that atomic volumes have long been known to be intimately connected with properties which are essentially those dependent on cohesion. Thus Tomlinson has shown a connection with thermal capacity,[*] and with Young's modulus of elasticity.[†] Sutherland [‡] found a close relation between the atomic volumes and the rigidity of metals, and considered that this rigidity is " in its essence a kinetic phenomenon almost as simple in character as the elasticity of perfect gases." Fessenden [§] regarded the cohesion of metals as proportional to some power of the atomic volume, a conclusion which is clearly of great interest in relation to the present inquiry.

[*] *Royal Society Proceedings*, 1884–85, vol. xxxviii. p. 488.
[†] *Royal Society Philosophical Transactions*, 1883, p. 32.
[‡] *Philosophical Magazine*, 1891, vol. xxxii. p. 41.
[§] *Chemical News*, 1892, vol. xvi. p. 206. *Journal of the Franklin Institute*, Sept., 1896.

In 1888 Roberts-Austen * showed that in the case of certain metallic impurities added to pure gold the influence of the atomic volumes of the impurities on the mechanical properties could be directly observed as an experimental fact.

As the result of extended researches on the changes of volume, refractive index, temperature, and solubility attending the mixing of liquids which do not react chemically, Holmes † has advanced a mechanical theory of the intermiscibility of liquids, based on the view that the liquid molecule retains its individuality in solution.

He has tabulated ‡ a number of organic liquids in the order of their molecular volumes as deduced from their relative complexities in the liquid state. The position of a liquid in this table decides its degree of miscibility with other liquids, those which are adjacent to each other being miscible in all proportions. When the ratio of the molecular spheres of any two liquids approximates to 1·7, he finds that a limited miscibility results, which becomes less and less as this ratio increases. He has found no exception to this rule, and concludes that " *there is little doubt that the intermiscibility of liquids is a function of molecular volume,* and that being independent of chemical constitution offers a means of ascertaining the molecular weights of liquids, comparable perhaps with those based on Avogadro's hypothesis for the gaseous state."

In applying these views to the consideration of the miscibility of metals we find that the knowledge of the molecular complexity of metals, or of metals alloyed with each other, is very limited, so that we are unable to say what the molecular volumes of molten metals are. Some attempts have been made to determine the complexity of the molecule. Roberts-Austen § determined the " atomic fall " of the freezing point of pure gold resulting from the addition of other metals (lead, bismuth, platinum, tin, manganese, aluminium, and silver) ; Heycock and Neville || studied the " atomic fall " of the freezing point of sodium by the addition of the elements—tin, bismuth, cadmium, lead, thorium, zinc, silver, and copper. The general conclusion from these investigations was that the added

* *Royal Society Transactions*, vol. clxxix. pp. 339–439.
† *Transactions of the Chemical Society*, 1906, p. 1774; 1913, p. 2147; 1915, p. 1471.
‡ *Ibid.*, Dec. 1913, p. 2164.
§ First Report of the Alloys Research Committee, *Proceedings of the Institution of Mechanical Engineers*, 1891, p. 562.
|| *Transactions of the Chemical Society*, 1889, p. 666.

metal in dilute solution exists as single atoms. Tammann [*] obtained similar results with amalgams. Grüneisen [†] considers that the assumption that solid metals and liquid mercury are monatomic is justified in consequence of a relation which he finds between compressibility (K), thermal expansion ($3a$), and the volume of the gram-atom (v). For 20 metals he finds that the expression $\dfrac{3av}{K}$ is practically a constant. Antimony and bismuth show the greatest deviation from the mean value.

It may be of significance that the reciprocals of the surface tensions of these two metals showed the greatest deviations from the corresponding atomic volumes.

Ramsay [‡] concluded, from the lowering of the vapour pressure of amalgams in accordance with Raoult's law, that it is " legitimate to infer that in solution the atom of the metal is, as a rule, identical with its molecule." In certain cases, those of tin, lead, antimony, and bismuth, he found a tendency towards association of atoms.

With regard to metals, therefore, it has become customary to speak of " atomic volumes " when molecular volumes are really implied. This is the case when considering miscibility. Thus Desch [§] has pointed out that in the following well-known pairs of metals which form complete series of solid solutions with one another, the components in each case have nearly equal " atomic volumes."

Gold	10·202
Silver	10·233
Gold	10·202
Copper	7·077
Copper	7·077
Manganese	7·44
Copper	7·077
Nickel	6·64
Platinum	9·06
Iridium	8·61

To these he might have added :

Gold	10·202
Platinum	9·060

[*] *Zeitschrift für physikalische Chemie*, 1889 (3), p. 441.
[†] *Annalen der Physik*, 1908 (iv.), vol. xxvi. pp. 393–402. *Journal of the Chemical Society*, 1908, ii. p. 563.
[‡] *Transactions of the Chemical Society*, 1889, pt. i. p. 521.
[§] *Transactions of the Faraday Society*, 1913, p. 251.

It is proposed to consider the behaviour of the constituents of the alloys of certain of these pairs of metals from the point of view of their intrinsic pressures and surface tensions. A property of these alloys which offers an interesting field for consideration in this connection is that of " liquation."

Liquation.

The property of ' liquation " is one which has long been known as a form of segregation which occurs during solidification. Hitherto, it has not been clearly distinguished from the segregation which occurs in eutectiferous alloys where the last portions to solidify are those of the lowest melting point.

The cases to which reference will now be made are those in which liquation occurs in certain alloys, and in which the first portions to solidify are those of *lowest* melting point. Such cases of liquation are met with when those portions nearest the containing vessel (or " mould " in which the metal is allowed to solidify) are chilled.

The apparent contradiction to theory which is involved in observations that in these cases the portions which solidify first are of such compositions that their freezing points must be lower than the freezing points of those portions which solidify last, has caused some hesitation in offering an explanation of this behaviour. Well-known cases of " liquation " of the type now under consideration are those of " standard silver " (925 Ag, 75 Cu) and " standard gold " (916·6 Au, 83·3 Cu) alloys.

These alloys when melted, thoroughly mixed, and cast in moulds invariably show an enrichment of precious metal towards the centre, *i.e.* to those portions which solidify last.

This behaviour has formed the subject of much experimental work by Roberts-Austen * and others † in their endeavours to obtain uniform " Trial Plates " against which to compare the fineness of gold and silver coinage.

The facts regarding the liquation of the silver-copper alloys were very clearly recognized by Roberts-Austen in 1875,‡ who

* Mint Reports, Nos. 1, 2, 3, 4, 29, 30, 31, and 32.
† Matthey, Burke, Koga, and Yamagata.
‡ *Proceedings of the Royal Society*, No. 162, 1875, p. 493.

then said, " The curve of fusibility shows that the alloys which contain less than 35 per cent. of silver have higher melting points than other alloys of silver and copper, or even of pure silver.   It would not appear, therefore, that liquation is the falling out of the least fusible alloy present in a mass of silver and copper ; for if it were, the external portions of the alloys would in all cases be less rich in silver than the centre." He pointed out that although the explanation of the molecular rearrangements in these alloys was not clear, they were " dependent to a great extent on the rate at which they are cooled " (solidified).

Roberts-Austen showed * that, in the case of the standard silver alloy, uniformity could be most nearly attained by prolonging the solidification over a long period, whereas Matthey † showed that the same result could be achieved by casting the alloy in a mould giving a thin plate, large in the other two dimensions and which, in consequence, solidified quickly.

These apparently contradictory results will be shown to be entirely consistent with the explanation which is now offered.

The two alloys which have been mentioned have been studied with great care, the methods of assay admitting of extreme accuracy in the determination of the proportions of the constituents in different parts of the same casting.   The alloys of gold and silver have also been examined from this point of view by Roberts-Austen and Rose.‡   Besides being miscible in all proportions, these alloys show no evidence of liquation under ordinary conditions of casting and solidification.

Other alloys have been similarly examined, but perhaps not so exhaustively as these three series.

Matthey,§ besides examining the silver-copper alloys from this point of view, also examined alloys of gold with platinum, with palladium, and with aluminium, and also alloys of platinum with palladium and with rhodium.   Gowland and Koga ‖ investigated the liquation in certain alloys of silver and bismuth.

Consideration will first be given, from the point of view of liquation in relation to surface tension and intrinsic pressure,

* *Proceedings of the Royal Society*, 1875, vol. clxii. pp. 481–495.
† *Ibid.*, 1894, vol. lv. pp. 265–269.
‡ *Ibid.*, 1902, vol. lxx. pp. 161–163.
§ *Ibid.*, 1890, vol. xlvii. pp. 180–186.   *Transactions of the Royal Society*, 1892, vol. clxxxiii. pp. 629–652.   *Proceedings of the Royal Society*, 1894, vol. lv. pp. 265–269.
‖ *Journal of the Chemical Society*, 1887, vol. li. p. 410.

to the solidification of the alloys which have already been mentioned—namely,

1. Silver-copper.
2. Gold-copper.
3. Gold-silver.

The first of these pairs shows marked evidence of liquation, whereas the last shows little, if any. The figures given by Traube for the intrinsic pressures, and the figures obtained in the course of this work for the surface tensions of the constituents of these alloys, are as follows :

	Intrinsic Pressure (megabars).	Surface Tension (dynes per cm.).
Copper	236,000	1178
Gold	178,500	1018
Silver	161,900	858

If we compare the ratios of these intrinsic pressures and surface tensions, we find the following results (given in parts per cent.) :

	Intrinsic Pressures.	Surface Tensions.
1. Silver-copper	41 : 59	43 : 57
2. Gold-copper	43 : 57	46 : 54
3. Silver-gold	46 : 54	46 : 54

Considering first the intrinsic pressures. Those which show the greatest difference, namely, silver-copper, are those which, when alloyed to form the " standard " alloys, show the greatest liquation effects. Gold and silver, which show the least difference in intrinsic pressures, also show least, if any, evidence of liquation. Gold and copper are intermediate in both respects, in spite of the fact that the melting points of its constituents are closer together than those of gold and silver.

Next, with regard to the surface tensions, the difference is again greatest in the case of silver and copper, while that of gold and silver is identical with the intrinsic pressures. The relation of gold and copper, however, appears to be the same as that of gold and silver. From its behaviour in respect to liquation, one would expect it to approximate much more closely to the gold-silver alloys than to those of silver and copper, but to show some difference, and revised determinations may show it to occupy such an intermediate position.

Before proceeding to consider other solid solutions which show these liquation effects, the views will be given which are put forward in explanation of these effects.

The occurrence of liquation of the type under consideration appears to afford a striking instance of the well-known principle of "mobile equilibrium" enunciated by Le Chatelier,* that "*when the state of a system is changed the system alters so as to oppose a greater resistance to that change.*"

Thus, in the case of molten standard silver (925 Ag, 75 Cu) cooling in a mould, the chilling which occurs at the edges of a section tends to change the state of the system from liquid to solid. Unless the conduction of heat is sufficiently rapid to equalize the temperature throughout the mass, the only way in which this tendency can be opposed is for the system to change, so that the portion affected may have a lower melting point and so remain fluid at that particular temperature. This can only be brought about by a change in the relative proportions of silver and copper—the copper increasing so that an alloy with a lower melting point is formed in this vicinity. Experience shows that this is precisely what happens, and it only remains to indicate reasons why it is possible for it to happen.

It is suggested that the explanation is to be found in the differing cohesions of the copper and silver molecules resulting in limited miscibility. Copper, in the liquid state, having a higher surface tension than silver, and a higher intrinsic pressure, its molecules have a greater affinity for each other than for the silver molecules. As the freezing point is approached, in virtue of their superior cohesion for each other, they are able, to some extent, to disentangle themselves from the silver molecules and to become available to displace an equivalent proportion of them in the periphery of the mass and so form a system of lower melting point, which is thus able to withstand solidification for a little longer than would otherwise be the case.

Having considered the silver-rich alloys of these two metals, it is interesting to consider the behaviour of the copper-rich alloys. On this side of the series we find that the liquation occurs in the opposite direction, that is, the last portions to solidify are richer in copper than the edges. Since the freezing points of pure silver or pure copper are each lowered by the addition of copper or silver respectively at either end of the series, it is clear that the explanation offered applies equally to copper-rich alloys—the copper and silver having different

* Lewis's "System of Physical Chemistry," vol. ii. p. 140.

intrinsic pressures, the copper molecules are able to withdraw themselves to some extent from the edges, and so to lower the freezing point. These occurrences of limited miscibility are therefore in accord with Walden's observations (cf. p. 82).

Before leaving the consideration of the silver-copper alloys, reference should be made to two facts which have always been of considerable interest to those who have worked on these alloys, namely, the coincidence of the eutectic alloy (Levol's alloy) with the formula of Ag_3Cu_2 and its freedom from liquation.

Although Friedrich and Leroux * claim to have extended the horizontal eutectic line of the equilibrium curve on either side of the composition corresponding to Ag_3Cu_2 to a point within 10 (atomic) per cent. of pure silver, still it should be remembered that Heycock and Neville † found no evidence of the eutectic up to 38 atoms per cent. of copper, or beyond 42·6 atoms per cent. of copper. The disposition, therefore, which has always existed to regard the composition corresponding to Ag_3Cu_2 as an exceptional case of an eutectic, if not as a true compound, may have some foundation in fact. A consideration of the relative intrinsic pressures and surface tensions of the constituents of this composition shows that if multiplied by their respective atomic percentages, 60 and 40, we arrive at figures which are approximately equal, and which therefore may be regarded as representing a state of equilibrium.

Thus :

Intrinsic pressures $\begin{cases} \text{Silver} &= 161{,}900 \times 60 = 9{,}714{,}000 \\ \text{Copper} &= 236{,}100 \times 40 = 9{,}444{,}000 \end{cases}$

Surface tensions $\begin{cases} \text{Silver} &= 858 \times 60 = 51{,}480 \\ \text{Copper} &= 1178 \times 40 = 47{,}120 \end{cases}$

Before leaving the consideration of alloys of silver in regard to liquation, mention should be made of the silver-cadmium alloys investigated by Rose.‡

The particular alloy which corresponds to " standard silver " (925 Ag, 75 Cd) was shown to be quite free from those disadvantages arising from liquation, which renders the silver-copper alloy untrustworthy as a standard of reference. The surface tension of molten cadmium has not yet been determined by the method described, but values have been given by earlier workers using other methods.

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* *Metallurgie*, 1907, vol. iv. p. 293.
† *Proceedings of the Royal Society*, 1897, vol. clxxxix. A., p. 33.
‡ *Ibid.*, 1904, vol. lxxiv. pp. 220-230.

Quincke has given 815 and Siedentopf 832, which indicates that it is not very different from silver (858). The fact that a solid solution of these two metals can exist without perceptible liquation is therefore in accordance with the observations already made.

Next, with regard to the alloys of silver with gold. Although the " standard " alloy (916·6 Au, 83·3 Ag) is found in practice to be homogeneous under the most critical methods of assay which are capable of detecting variations in parts per 100,000, the silver-rich alloy (say, 900 Ag, 100 Au) has not been critically examined from the point of view of liquation.

The intrinsic pressures of these two metals, and also their surface tensions, are much closer together than those of silver and copper, although by no means identical.

It should be possible, therefore, under suitable experimental conditions, to arrange that liquation should also appear in these alloys. The conditions required would be, that rapid cooling of one part of a continuous liquid mass should be accompanied by very slow cooling of the part remote from it.*

In many forms of industrial practice these are conditions which occur of necessity and are unavoidable.

Other examples will now be given of alloys which show liquation, and to which the views given above appear to be applicable.

Matthey † has shown that in the solidification of gold-platinum alloys the centre of a sphere of the metal is always richer in platinum than the portions near the circumference, whether the mass be mainly gold or mainly platinum.

This appears at first sight in contradiction to the observations in the case of the silver-copper alloys, but since these results were obtained the equilibrium diagram for the gold-platinum alloys has been investigated by Doerinckel,‡ who has shown that these metals are isomorphous and form a series in which the freezing points of the alloys lie entirely between the freezing points of the pure metals.

The significance of this fact in relation to liquation effects is, of course, that whatever may be the composition of the alloy under consideration, the only way in which molecular move-

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* Moissan records the observation that in chilling molten silver (containing small quantities of gold) from very high temperatures, the gold "gathers into the still liquid central part." "The Electric Furnace," English translation, 1904, p. 135.

† *Proceedings of the Royal Society,* 1890, vol. xlvii. pp. 180–186 ; and *Philosophical Transactions,* 1892, vol. 83 A., pp. 629–652.

‡ *Zeitschrift für anorganische Chemie,* 1907, vol. liv. p. 333.

ments can adjust the composition of the exterior portions to a falling temperature is by increasing the proportion of gold to platinum in those portions.

In this series of alloys, the difference between the intrinsic pressures of the components is very much greater than in those cases which have been previously considered.

Thus : Platinum = 324,200 megabars
       Gold   = 178,500   ,,

From the reasoning which has been applied to the other cases, we should expect to find greater liquation effects in these alloys. Matthey's work * showed that this is actually the case. He found a maximum difference of 58 parts per 1000 between the centre and the mean of the outside of a casting containing 900 parts of gold and 100 parts of platinum per 1000, a variation which is far in excess of anything which has been recorded in the case of silver-copper or gold-copper alloys.

EQUILIBRIUM OF INTERNAL PRESSURES.

The evidence of equilibrium shown by the application of values for the intrinsic pressures and surface tensions to the case of the silver-copper alloy corresponding to the composition Ag_3Cu_2, has encouraged the hope that similar relations of equilibrium might be found in other alloys. The case of the alloys of copper and zinc has been examined from this point of view.

By calorimetric work, Baker † has shown that the action of solvents on copper-zinc alloys indicates a maximum heat development at a composition corresponding to $CuZn_2$. This composition falls within the range of the hard γ-alloys (30 to 40 per cent. Cu). The values given by Traube for the intrinsic pressures of these metals, multiplied by the corresponding atomic percentages, give the following figures :

Copper .   .   .   .   . $236,000 \times 33\frac{1}{3} = 7,867,000$
Zinc   .   .   .   .   . $108,900 \times 66\frac{2}{3} = 7,260,000$

The corresponding surface tensions give :

Copper .   .   .   .   . $1178 \times 33\frac{1}{3} = 39,266$
Zinc   .   .   .   .   . $707 \times 66\frac{2}{3} = 47,132$

The most striking application of Traube's figures, however,

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* *Philosophical Transactions of the Royal Society*, 1892, vol. 183 A., pp. 629–652.
† *Ibid.*, 1901, 196 A., p. 529.

is to be seen in the eutectoid of carbon and iron, namely, steel which contains 0·89 per cent. (by weight) of carbon. Steel of this composition, at temperatures above 690° C., consists of a homogeneous solid solution, and if quenched above this temperature is glass-hard. On cooling to 690° C. from higher temperatures, however, the solid solution breaks up into the well-known " pearlite," a finely laminated conglomerate of iron and iron carbide. The change is accompanied by a maximum development of heat or " recalescence." If the percentages of the constituents of this particular steel be recalculated to *atomic* percentages, it is found that the composition becomes :

Iron	95·98 atoms per cent.
Carbon	4·02 ,, ,,

The figures given by Traube for the intrinsic pressures of these elements are :

Iron	239,000 megabars
Carbon (diamond) . . .	5,458,000 ,,

Multiplying the atoms per cent. of each element by its corresponding intrinsic pressure, we arrive at figures which are approximately equal :

Iron	22,939,220
Carbon	21,941,160

They may be expressed as a ratio of 51·1 to 48·9.

The alloy of this composition is known to be the limit of saturation of iron and iron carbide, and therefore one of equilibrium. The interest and significance of the coincidence of the above figures lies, of course, in the support which it might be regarded as giving to the view that in steel at temperatures above 690° C., and in steel quenched above this temperature, the carbon exists in the allotropic or " diamond " condition.

Reference will be made to this matter again in discussing hardness (p. 97).

Surface Tension, Internal Pressure, and the Hardness of Solid Solutions.

In the brief reference to hardness in relation to pure metals given on p. 76, it has been said that the increase of hardness which occurs when metals, which form solid solutions, are alloyed,

is clearly of the nature of a molecular "rapprochement." This increase of hardness, so far as observations have been made, is not found to be accompanied by any appreciable increase in density. Desch has pointed out,* in his review of the facts relating to the hardness of solid solutions, that this seems to exclude any important differences in the closeness of packing of the molecules. This view, however, calls for closer scrutiny, having regard to the significance attaching to even small changes of density, to which attention has been directed on p. 77. He also refers to a statement made by Tammann,† that the increased hardness of solid solutions is due to "the attractive force between two different molecules being always greater than the attractive force between two similar molecules in the same mixture." He concludes from this statement that "the attraction, and consequently the hardness, should be a maximum in the solid solution containing equimolecular proportions of the two components." In support of this view he quotes the work of Kurnakow and Zemczuzny,‡ whose examination of the hardness of solid solutions does certainly show that the maxima occur in the *neighbourhood* of equimolecular proportions.

They did not attempt to stress this point, however, or to draw any conclusions from it, and a scrutiny of their results shows that without some amplification of their work such a precise conclusion would not be justified. In the absence of evidence in support of Tammann's view of molecular attractions in solid solutions, the molecules of one constituent may, however, be regarded as the *attracting* molecules, and those of the other constituent as the *attracted* molecules.

The mutual attraction or intrinsic pressure in such a system would be proportional to the product of the numbers of *attracting* and *attracted* molecules.

In a solid solution of two metals having different intrinsic pressures, this product, and therefore the cohesion and those properties dependent on it, should be at a maximum when the relative intrinsic pressures of the constituents are equal. This is clearly not the case when the proportions are equimolecular, although it so happens that it is nearly so in the case of gold and

* *Journal of the Faraday Society*, 1914.
† *Lehrbuch der Metallographie*, Leipzig, 1914, p. 332.
‡ *Zeitschrift für anorganische Chemie*, 1908, vol. lx. pp. 1–37.

silver, to which particular attention has been directed by Desch and others.

Considering, then, this case of gold and silver, the relative intrinsic pressures in the alloy may be regarded as being proportional to the product of their respective intrinsic pressures (as pure metals) and their respective atomic percentages in the alloy. When these relative pressures are equal the product—that is, the intrinsic pressure of the alloy—should reach a maximum.

Simple calculation from the values given by Traube, viz. :

Gold	178,500 megabars
Silver	161,900 ,,

shows that this condition is fulfilled when the composition of the alloy corresponds to—

Gold	47·9 atoms per cent.
Silver	52·1 ,, ,,

The proportion by weight is, roughly, two parts of gold to one of silver, which is recognized in practice to be the hardest alloy of the series.

A similar calculation, using the values for surface tension instead of those for intrinsic pressure, shows a fair agreement with the above, although from the nature of the data and the fact that the surface tensions are not directly proportional to the intrinsic pressures, anything more than a general agreement could not be expected.

The values for the surface tensions being—

Gold	1018 dynes per sq. cm.
Silver	858 ,, ,, ,,

the composition corresponding to maximum cohesion is—

Gold	46·3 atoms per cent.
Silver	53·7 ,, ,,

These compositions are sufficiently near to the supposed equi-molecular proportions observed by Kurnakow and Zemczuzny, having regard to the fact that between 30 atoms per cent. and 65 atoms per cent. of gold they record only one measurement of hardness, namely, that at 50 atoms per cent.

Similarly, in regard to the alloys of gold and copper, this is the only measurement recorded between 30 and 65 atoms per

cent. of gold. The compositions of maximum cohesion as in-dicated by intrinsic pressures and surface tensions respectively in this case are :

| Gold | . | . | . | . | . | 56·9 atoms per cent. |
| Copper | . | . | . | . | . | 43·1 ,, ,, |

and

| Gold | . | . | . | . | . | 51·3 ,, ,, |
| Copper | . | . | . | . | . | 48·7 ,, ,, |

In the case of copper and nickel, the only figures which can be given are those derived from the intrinsic pressures, as the surface tension of molten nickel has not yet been determined. The composition indicated as having a maximum cohesion is :

| Copper | . | . | . | . | . | 56·47 atoms per cent. |
| Nickel | . | . | . | . | . | 43·53 ,, ,, |

In view of the above considerations, the cases of equilibrium shown by the two alloys already considered on pp. 91 and 93, and corresponding to the compositions Ag_3Cu_2 and $CuZn_2$, may be examined from the point of view of cohesion and hardness.

It is then found that the silver-copper alloy which should result in a maximum hardness corresponds to :

| Silver | . | . | . | . | . | 59·3 atoms per cent. |
| Copper | . | . | . | . | . | 40·7 ,, ,, |

Having regard to the character of the data, this is a very close approximation to the composition Ag_3Cu_2 (Ag 60 atoms per cent., Cu 40 atoms per cent.), and therefore corresponds with what is known to show maximum hardness.

With regard to the case of the alloy corresponding to the composition $CuZn_2$, similar treatment leads to the conclusion that, with the data available, maximum hardness is indicated at the composition :

| Copper | . | . | . | . | . | 31·5 atoms per cent. |
| Zinc | . | . | . | . | . | 68·5 ,, ,, |

The γ-alloys ranging from 30 to 40 per cent. of copper in this series are known to be extremely hard and brittle. Turner * records a maximum hardness, however, at the upper limit of the range.

The striking instance of iron and carbon, to which reference has already been made (p. 94), can be approached from this point of view, which is the reverse of that already considered.

Thus the solid solution in which the product of the relative

* *Journal of the Institute of Metals*, No. 2, 1909, vol. ii. p. 129.

intrinsic pressures should attain a maximum, regarding the
carbon as being in the form of the diamond allotrope, may be
calculated from Traube's figures for the intrinsic pressures :

Iron	239,000 megabars
Carbon (diamond) . . .	5,458,000 ,,

From these values the composition, which is indicated as having
the maximum cohesion, is that of :

Iron	95·81 atoms per cent.
Carbon	4·19 ,, ,,

which approximates very closely to the composition :

Iron	95·98 atoms per cent.
Carbon	4·02 ,, ,,

which is that of the eutectoid—pearlite—having the percentage
composition by weight :

Iron	99·11
Carbon	0·89

Surface Tension in Relation to Alloys other than Solid Solutions.

With regard to the numerous classes of alloys which do not
form solid solutions, but consist of two or more constituents,
forming a heterogeneous mixture, it is believed that a knowledge
of their surface tensions in the molten state considered in con-
junction with the surface tensions of their constituents, whether
these may be eutectics or compounds, will throw more light on
their behaviour and constitution and afford an explanation of
their structures as revealed by the microscope. Those binary
alloys, for instance, which at particular compositions consist
wholly of a " eutectic " of the constituents, having a relatively
low melting point, do not, as a rule, afford suitable properties
for industrial use. A knowledge, however, of the effect of the
presence of the eutectic in an alloy, in a more or less degree, is of
considerable importance in relation to the resulting properties.

The values of the surface tensions of such eutectics may afford
some explanation of the marked differences in the relative sizes
which these eutectics present when examined micrographically.

The appearance under the microscope of those alloys, which

in structure resemble "emulsions," strongly suggests that the relative surface tensions of the constituents have a determining effect on the form and size which they assume on solidification, and consequently on the properties of the alloys which result. It is well known that the structural constituents of alloys in such cases determine their properties rather than the ultimate components shown by analysis.

In many cases the addition of a certain, often small, proportion of a third element has a profound effect on the structural character of a harmful constituent—for instance, in the elimination of the eutectic structure by the addition of tin to copper containing phosphorus, or by the addition of arsenic to copper containing oxygen. The changes in microstructure which are thus brought about give striking evidence of aggregations into globular forms resulting from changes of surface tension.

The experiments of Darling * on the formation of spheres of liquid, and the movements of semi-oily liquids on a water surface resulting from changes in surface tension, indicate some interesting analogies to certain types of heterogeneous alloys. The behaviour of the globules of certain liquids in others in which they are slightly soluble, or in relation to which they have different coefficients of expansion, closely resembles the appearances which are well known in certain alloys. The manner in which the globules break into smaller globules or aggregate into larger globules and the reniform shapes which represent intermediate stages, all have their counterparts in alloys.

These considerations, however, lead to the complex relations of composite fluid surfaces, which require treatment by physical methods before their interpretation and metallurgical significance can be brought into agreement.

Summary.

1. A relation has been shown between the surface tensions of molten metals, as derived from capillary depressions, and the internal pressures calculated by Traube from his application of Van der Waals' equation to the solid state.

2. Certain work which bears on the relationship between

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* *Nature*, 1911, p. 512; and 1912, p. 419.

surface tension, internal pressure, compressibility and atomic volume has been collected and discussed.

3. Some recent work on the theory of solution has been considered in relation to the intermiscibility of metals and the formation of solid solutions.

4. An explanation of the phenomenon of liquation in certain alloys, based upon these views, is suggested.

5. Consideration has been directed to the hardness of certain solid solutions from the point of view of internal pressures.

6. Some remarks are offered regarding certain alloys, other than solid solutions, from the point of view of the surface tensions of their constituents.

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LIQUATION.

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DISCUSSION.

Sir Thomas Rose, D.Sc., Vice-President, in opening the discussion, thought the author was to be congratulated on his excellent paper, which indicated a great amount of close study. As a result of his work on the surface tension of metals, the degree of D.Sc. had been conferred on Dr. Smith, and it was pleasant to remember that all that work had been communicated to the Institute. The paper lent itself more to discussion by correspondence than by speech, but there were a few points on which he would venture to touch. In the first place, he desired to commend the author for the courage he had shown ; he had put forward some very heterodox opinions, and he evidently expected the members not to condemn them hastily, but to ask themselves whether it was not a good thing sometimes that their most cherished convictions should be called in question, so that they might have an opportunity of going over again the reasons on which they were based. For example, the statement was made on p. 77 : " This conclusion indicates, therefore, that the effects of cold work in producing a relatively small increase in density will involve a correspondingly great increase of internal pressure, and of those attributes dependent on it." The author there appeared to ask the members to put on one side a large number of very careful determinations of density of cold-worked and annealed material, all of which went to show that on cold working, or on compression, the metal became less dense, and that on annealing the density was increased. In exchange, all he offered were some theoretical considerations as to internal pressure and intermolecular space, and no experimental data were given in support of them. It appeared to him it was for the author to give that support, as otherwise it might be necessary to argue in the following fashion : that when the metal was compressed by an external force the intermolecular space was diminished, the internal pressure and the density were increased, but only temporarily, and, on the removal of the external pressure, the metal expanded again, and if part had been changed into the amorphous state, the density would be less than before. Theory must agree with observed facts, and he thought it was desirable that the author should give observed facts in support of his theory.

In the Table of Relationships set out on p. 78, the author gave Bottone's hardness figures, which agreed with those for atomic concentration. Bottone considered that hardness of metals was measured by the depth to which a cylinder penetrated under a constant force. Personally he hoped the ideas of the members on hardness would be made clearer by the Committee that was now dealing with the subject. For example, skin hardness should be distinguished from the mean hardness of a piece of metal. Skin hardness, as measured by Professor

Turner's instrument and by Shore's scleroscope, was probably the main property on which abrasion and perhaps the first machining depended. The mean hardness measurable by Brinell's ball and Ludwik's cone was the main property on which resistance to deformation depended. On work-hardened materials skin hardness and mean hardness were quite different, but on annealed or cast metals such as Bottone and Professor Turner had dealt with there was no difference of that sort. It was found that the Brinell ball-test and Ludwik's cone-test agreed far more closely with Turner's figures than with Bottone's figures, and if there was any relationship between hardness and atomic concentration, a much better agreement would be obtained by comparing the hardness figures of the metals and the cubes of the numbers denoting atomic concentrations, not the numbers themselves. He left it to the author to explain that relationship.

On p. 87 the author gave a fascinating theory of the behaviour of the silver-copper and kindred alloys on solidification. No one had attempted to explain it before. There was liquation, and in silver-rich alloys, silver was concentrated towards the centre and copper towards the outside. He desired to say a word of warning in regard to the statement set out on p. 88 on the authority of Matthey, that uniformity of composition was obtained in standard silver (silver 925, copper 75) by rapid cooling. In 1899, when the Mint had to prepare standard silver trial plates of uniform composition for testing coins, Matthey's method was tried, and the Mint had all the assistance that Mr. Matthey could give. Many experiments were made, and they were all a hopeless failure. It might be inferred from Gulliver's more recent work on "The Effect of Rapid Cooling on the Constitution of Alloys" that the method was foredoomed to failure. The more rapid the solidification, the more a solid solution was split up into alpha, beta, and gamma phases; while the slower the solidification the more prominent the alphas became and the more the others were suppressed. That was in accordance with theoretical considerations which he submitted agreed with practice. He sometimes wondered whether sufficient importance had been attached to Gulliver's work. Gulliver came to some most important conclusions, which were disregarded, and by implication condemned, in the best books that had been written on Metallography. When a really useful hypothesis was enunciated, such as those put forth by Professor Gulliver or Dr. Smith, advantage did not seem to be taken of their work. The explanation given by the author seemed to indicate not that the inside of an ingot solidified before the outside, but that there was a tendency for all parts of an ingot to solidify almost simultaneously. He was speaking, of course, of solid solutions. It was rather a remarkable application of Le Chatelier's theory, but it worked in very well. In the case of the silver-copper alloys, it explained why it should be allowed to cool slowly instead of quickly. If it was cooled quickly there was much more tendency for liquation to take place than if it was cooled slowly. He desired to

mention in that connection that they now knew that a promising method of making uniform silver trial plates was to anneal at, say, 700° for a sufficient length of time. Another point he desired to mention was that it was usually assumed that if there was rapid solidification of a solid solution, small crystals would be formed, whereas if there was slow solidification, large crystals would be formed. If a solid solution was cast in an iron mould (chill casting), in some cases at least large crystals were formed on the outside where there was contact with the mould, whereas on the inside, where the solidification might be expected to be slower, small crystals were formed. He had photographs in his possession showing that result. Obviously, if there was slow cooling, it might be the case that crystallization started at a larger number of points, and smaller crystals resulted.

In conclusion, he expressed the hope that Dr. Smith would continue his work on surface tension, when he had time to spare after the war, and in particular would find occasion to supply some further experimental data.

Dr. F. C. Thompson (Sheffield) said that he considered that the paper was one of the most interesting he had ever read. It was worthy to be compared with the First Report which Dr. Desch presented to the Beilby Research Committee on " The Solidification of Metals from the Liquid State," and higher praise than that it would be almost impossible to give. The existence of surface tension in metals and its effects on their mechanical properties were questions to which he had given a considerable amount of attention during recent years ; and quite a large amount of the quantitative work he had been able to do was based on the figures contained in the author's earlier paper. One of the conclusions he had arrived at was that the elastic limit of a metal was determined chiefly by the inter-crystalline boundaries across which surface tension was assumed to act—in other words, the elastic limit of a metal was more or less dependent directly upon surface tension. The work of Traube and others had shown almost beyond doubt that the tensile strength, or the hardness of a metal, was determined by the intrinsic pressure of the crystalline portion. If the conclusion the author had arrived at was true, that surface tension and intrinsic pressure bore an extremely simple relation to each other, it should follow that the elastic limit was always a certain definite ratio of the maximum stress, and, as was well known, that was not the case. Consequently it made him doubt whether the relationship between surface tension and intrinsic pressure was so close as the author appeared to imagine. In considering the table on p. 71, the internal pressures for antimony and bismuth were not recorded, but in a paper which Dr. Lewis read before the Faraday Society in 1911 some results of Traube's on the intrinsic pressure of antimony and bismuth were given.* The figure for bismuth was

* *Transactions of the Faraday Society*, 1911, vol. vii. p. 94.

97,300, and for antimony 117,700, results which were very different from those arrived at by the author. Not only were the results three or four times as great as those which would follow from the author's curve, but they were also in the opposite direction, the intrinsic pressure of antimony being bigger, according to Traube's result, than that of bismuth; consequently he was inclined to doubt whether the relationship between surface tension and intrinsic pressure was so close as appeared from the paper. A large number of questions might be considered in connection with the paper, but the only one to which he would refer at the present moment was in connection with the influence of atomic volume, which was constantly referred to. In that connection Roberts-Austen's generalization was reproduced. From the paper which he (Dr. Thompson) had presented to the Faraday Society * there appeared to be very grave reason to doubt the conclusion at which Roberts-Austen arrived. Considering those cases in which a solid solution was obtained, and these alone could be expected to yield results of a simple character, there seemed every reason to believe that the hardness of one metal was always increased by the solution in it of another, whether the atomic volume of the other metal was greater or less than that of the solvent. Some work of Professor Arnold, published in the *Journal of the Iron and Steel Institute* for 1894, amply proved that for iron, the material being hardened whether the atomic value of the alloying element was greater or less than that of the iron itself. He (Dr. Thompson) tried to explain this universal hardening in the following manner: Taking the solvent metal to start with, and introducing another metal into it, was equivalent to the replacement of certain atoms in the space lattice of the material by other atoms of the new component. There was every reason to believe, from recent experiments, that when two materials crystallized together in solid solution, the atomic volumes, or the molecular volumes, as the case might be, were made to coincide; *i.e.* if there was a solid solution of two metals A and B, of which the atomic volume of A was bigger than that of B, then the atomic volume of A had to decrease, and the atomic volume of B had to increase until coincidence occurred, and as a result elastic stresses were obtained throughout the whole mass, to which stresses the increased hardness was ascribed. That assumption was capable of a certain amount of quantitative and mathematical treatment, and when that was carried out it was found, for instance, that the hardness concentration curve of a complete series of solid solutions, such as the gold-silver alloys, was parabolic, as had been determined in practice. It was also found that the maximum hardness was at the 50 : 50 composition. He had made some rough estimates of the actual intrinsic pressure in the case of special solid solutions, and in the case of a 50 : 50 gold-silver alloy they came out remarkably close to what must

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* *Transactions of the Faraday Society*, vol. xii. pt. i.

necessarily be the case from Traube's work. It was unnecessary, therefore, to appeal to surface tension, especially in connection with the internal structure of a crystal where no surface of separation was presented.

Mr. JOHN DEWRANCE, Member of Council, said that crystallization from the centre or from the outside of a casting was extremely obvious in the bronze alloys. There were conditions of heat treatment, or something which it was very difficult to determine, which decided the crystals to form either from the outside of the casting or from the centre of the casting. If the crystals were formed from the centre, the contraction on crystallization caused small cysts where air was drawn in from the mould or from the outside ; these cysts could be filled with oil by dipping the casting hot into oil, proving there were outlets to the surface. If, on the other hand, the crystallization began from the outside to the centre, then the contraction took place in the centre of the casting, the eutectic being driven to the centre, and perhaps a space showing where the contraction had pulled the metal apart. Dr. Thompson had mentioned the way in which one metal might be interposed among the crystals. It was found that where a proportion of lead exceeding 1 per cent. was put into bronze, a rich lead alloy seemed to be interposed between the major crystals, and it was very often driven to the outside and formed a complete skin. When even 1 per cent. of lead had been added, by breaking the casting it was possible to see that the lead had been driven from the centre of the casting to the extreme edge. There was a layer which was distinctly of a different crystallization and of a different colour to the remainder of the casting.

Dr. S. W. SMITH, in reply, said that Sir Thomas Rose had commended him for courage in bringing forward for discussion opinions of a heterodox character. He had done so because he ventured to think that there were questions arising from them which ought to be considered, and some attempt made to solve them. At any other time he would have apologized to the Institute for bringing forward a paper in which no new experimental work was recorded, but under the present circumstances he asked for indulgence.

Sir Thomas Rose had referred to certain determinations from which the inference had been drawn that cold work resulted in a diminution of density. He (the author) had tried to reconcile those determinations with other known facts, but he had not succeeded in doing so. He ventured to ask the question, whether all normal forms of cold work (excluding excessive wire-drawing) producing an increase of hardness, did not also result in an increase of density ?

With regard to the question of liquation, he had referred to the methods adopted by Matthey and by Roberts-Austen for obtaining a uniform silver-copper " trial " plate as being apparently opposed in

principle, but the facts were that by neither method was absolute uniformity attained.

He thanked Dr. Thompson for his favourable view of the paper as a whole.

His remarks concerning his own work on the elastic limit and the inter-crystalline boundaries were of great interest and importance, but beyond an acknowledgment of Dr. Thompson's work he had not been able to deal with those questions within the scope of the paper.

With regard to the figures for the intrinsic pressures of bismuth and antimony, quoted from a paper by Lewis, he thought that some slight confusion may have arisen, which he hoped a closer scrutiny would clear up.

Dr. Thompson had referred to his own conception of the increased hardness of solid solutions as the result of alloying pure metals. The theory, as he (the author) understood it, was that on the solidification of a mixture of two metals, resulting in a solid solution harder than either of the constituents, the atomic volumes of those constituents, in some extraordinary way, tended to approximate to one another. He found it difficult to understand that proposition, but the great interest attaching to Dr. Thompson's view was that, although he opposed the conclusion which had been reached by Roberts-Austen in 1888, that " there is some relation between the influence exerted by metallic impurities and their atomic volumes," yet he actually sought to explain the behaviour of solid solutions as resulting from differing atomic volumes. He had already taken the opportunity of pointing that out to Dr. Thompson in a contribution to the discussion which followed his paper to the Faraday Society in May last. Dr. Thompson's considerations of the mechanism of the influence of the added element involved the conception that the atomic volumes tend to become equal, the atomic volumes being clearly regarded as the important factors. Roberts-Austen had attempted to show that the influence of the added element was related to its atomic volume. In reality, therefore, Dr. Thompson's conception was an attempt to explain the views held by Roberts-Austen and based upon his experimental work in 1888.

The values for the intrinsic pressures arrived at by Traube, which the author had discussed in relation to certain other properties, were all derived from the atomic volumes.

He ventured to think that the attitude taken up by Roberts-Austen in 1888 would be vindicated, and that the atomic volume would be shown to be the determining factor in the behaviour of these alloys.

COMMUNICATIONS.

Mr. J. N. GREENWOOD (Manchester) wrote that any paper which tended to throw light on the most important property of metals, namely, their great cohesion, should be welcomed by scientists in general, and by members of this Institute in particular.

Naturally, before any theoretical deduction would be accepted as a working hypothesis, it was necessary to show in what way, and to what extent, it was in accordance with already well-established facts. It was as a summary of the relationships obtaining, between the intrinsic pressures and surface tensions on one hand, and the well-known physical properties of metals on the other hand, that the present paper was particularly valuable.

From this point of view, it was distinctly disappointing to find the calculation on p. 94 (in connection with the eutectoid alloy of iron and carbon) referred to as " the most striking application of Traube's figures." To the writer it seemed that such calculations were very misleading, especially to students. On this account he would discuss it somewhat fully. It appeared to rest on three assumptions, namely :

(*a*) That carbon existed in the solid solution as the free element.

(*b*) That it existed in solution as the allotropic modification—diamond.

(*c*) That the intrinsic pressures referred to the quenched solution, *i.e.* to an unstable state.

None of these assumptions appeared to be warranted. As regards (*a*) and (*b*), there was ample evidence that the carbon was in solution as iron carbide. He (Mr. Greenwood) would like to ask, whether there was any known connection between the intrinsic pressure of a compound and those of its components ? As regards the last assumption (*c*), he thought that the intrinsic pressures referred rather to stable states. In this case the maximum hardness was not attained at the eutectoid composition.

It was rather remarkable that Traube also used iron carbon alloys as an illustration of the application of his figures, namely, to calculate the limit of solubility (solid solution) of carbon in iron (*a*-iron, as now known). Curiously enough, by considering that the carbon was in solution as *graphite*, he found the same limit of solubility as had previously been proposed by Benedicks, *i.e.* 0·29 per cent. Applying the same method to copper-aluminium alloys, and assuming—as evidence pointed to—that the *a* solution was a solution of Cu_3Al in copper, he (Mr. Greenwood) found a limiting solubility of 1·4 per cent. aluminium (by weight), whereas it was well known that the limit of the *a* solution was about 9 per cent. aluminium.

Regarding the hardness of solid solutions, it would be interesting to know how Dr. Smith explained the increasing hardness of certain

solid solutions as the percentage of added element increased, when there was a corresponding increase in specific volume. This scarcely seemed compatible with the idea of "molecular rapprochement."

Another point which called for discussion was the statement (p. 76) that, "It is difficult to conceive of this change [permanent deformation] being unaccompanied by volume changes resulting from atomic or molecular compression." As it stood, the writer agreed with this statement, but he did not agree with the suggestion which ran through the succeeding paragraphs, namely, that these were the only volume changes which took place. This amounted to an unsupported refusal of the data obtained by numerous investigators, and collected by Beilby in several papers, as well as of the accumulated experience in the practical cold working of metals. As regards the latter, the writer was well aware of the danger of accepting such evidence as the decreased density of cold-drawn wires—as the apparent increase in volume might be due to internal rupture. But if the metal was restored to its maximum density by a short annealing, it appeared to him (Mr. Greenwood) that the possibility of internal flaws was in such cases removed. The work of Kahlbaum on cold-drawn platinum was perhaps the best example of this. The writer would suggest that there were two distinct volume changes—

(*a*) A decrease due to the compression of the atoms or molecules.

(*b*) An increase due to the breaking up of the crystal units, thereby giving rise to a disorderly arrangement of the molecules (Beilby's theory of an amorphous phase).

Since these two were probably different functions of the amount of permanent deformation, it was quite conceivable that in gradually increasing the amount of cold work one change would overtake the other. Hence although with the first application of pressure a decrease in volume might be noted, on continuing further Δv might pass through zero (when the two effects neutralized each other) and then become positive.

There was just one other point to which he (Mr. Greenwood) would like to refer. In the curve (p. 71) showing the relationship between intrinsic pressure and surface tension, aluminium fell considerably off the straight line. Could Dr. Smith offer any explanation of this? Was it due to experimental errors in the determination of the surface tension or of the constants used for calculating the intrinsic pressures? This was a point of particular interest to him at the present time.

Sir ROBERT HADFIELD, Bart., F.R.S., Member of Council, wrote that he noticed on p. 76 a reference to surface tension and hardness, and that the author said it was evident this hardness was intimately connected with cohesion. Does this mean that as cohesion increased so should hardness? It was found that as hardness increased cohesion

did also, but only to a certain point.   For example, there were certain kinds of steel which hardened well upon quenching, the result being glass scratching hardness, but the tenacity was reduced.   At any rate steel having, say, 550 Brinell ball hardness number—this being under glass scratching hardness—had a higher tenacity.   The same steel at, say, 620 ball hardness number, which was just beyond glass scratching hardness, as a rule had less tenacity.   The fact was that the results of observation seemed to show that the two would not go together as might have been expected.

With the author's form of expression he agreed theoretically, but in practice the two did not seem to go together.   He would like to know whether anything of this nature had been observed.   Perhaps, too, a different meaning was attributed to the term " cohesion " from that indicated above.

The table given on p. 78 was most interesting.   Had Dr. Smith any idea what would be the figures for cobalt under the different headings mentioned ?

The remarks on p. 94 were particularly interesting.   The idea has always been a fascinating one, that hardened steel might represent carbon, changed to the adamantine form embedded in the matrix, iron.

It was certainly curious to find that the intrinsic pressures of iron and carbon worked out about the same in a 0·89 per cent. carbon steel.   On the other hand, it might be mentioned that in alloy steels, for example one of, say, the following composition :

Carbon.	Chromium.	Nickel.
0·65 per cent.	2·00 per cent.	2·00 per cent.

although the carbon was considerably below the saturation point, yet it was possible to obtain by quenching quite as much hardness as carbon steel containing the higher percentage of carbon mentioned.

What would be the intrinsic pressures for such a steel as that above mentioned, also for manganese steel with, say, 1·25 per cent. carbon and 14 per cent. manganese ?

Mr. D. Hanson, M.Sc. (Teddington), wrote expressing his appreciation of Dr. Smith's paper, which approached many problems connected with metals and alloys in quite a new manner.   The application of physico-chemical methods to metallurgical investigations would have to be adopted to a very much larger extent in the future than it had been in the past, and Dr. Smith's paper, which could be considered a pioneering effort in this almost unexplored field, had raised a number of problems hitherto unconsidered.   Most of these problems, which were of intense theoretical interest, were, naturally, not completely solved, and much more experimental work would be needed, but the thanks of metallurgists were due to Dr. Smith for a paper full of suggestion.

He (Mr. Hanson) wished to discuss one or two points raised in

the paper. It seemed to him that in dealing with an essentially crystalline substance such as a piece of metal, a considerable amount of caution should be adopted in assuming any continuity of properties in the liquid and solid states, more especially in considering those properties of a metal which may be regarded as essentially those of a crystalline as distinct from an amorphous material. Where, for example, cohesion or tensile strength are considered during the operation of tensile fracture, we are probably not dealing with a material which is purely crystalline or purely amorphous, but with a complex consisting of both, and the cohesion or strength of the material will depend on the parts which these two phases play in the mechanism of deformation and fracture. As regards the amorphous phase, it seems very probable that there is definite continuity of properties from the liquid to the so-called solid state, since the amorphous material is to be regarded as undercooled liquid, structureless and of high viscosity. The known differences in the properties of amorphous and crystalline metal make it probable that for the crystals themselves there is marked discontinuity from liquid to solid. The work of Bengough,* and Bengough and Hanson,† on the properties of certain metals and alloys at high temperatures, shows that there is a sharp discontinuity in the tensile strengths of alloys as they approach the melting point, and microscopic evidence indicates that this discontinuity in properties is caused by differences between the amorphous and crystalline metal. The tensile test, however, is open to some objection as a measure of molecular cohesion in the cold, since continuous disintegration of the crystalline, with the formation of amorphous metal, is going on during the test, and the final result is influenced by factors whose relative importance is unknown. Determinations of the elastic limit would seem to offer much more reliable data for determining the molecular cohesion of metals.

There was one other point to which he wished to refer, and that was the explanation given by Dr. Smith to account for liquation in certain alloys. In the first place, the application of the Le Chatelier principle of mobile equilibrium to a system undergoing a charge cannot be made before that change commences. Further, the application of this " principle " to the alloys under discussion would lead to the directly opposite result to that found experimentally. For example, a silver rich copper-silver alloy, freezing normally, would first deposit crystals richer in silver than the alloy itself, thereby leaving a mother liquor poorer in silver, and therefore of a lower melting point. In other words, " the system would alter itself so as to oppose a greater resistance to the change." Cases of liquation are, however, not uncommon. The writer has observed this phenomenon on a number of occasions in alloys of copper with aluminium. In alloys containing 10 to 12 per cent. copper, differences of 1 per cent. in the copper content

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* Bengough, *Journal of the Institute of Metals*, No. 1, 1912, vol. vii. p. 123.
† Bengough and Hanson, *Journal of the Institute of Metals*, No. 2, 1914, vol. xii. p. 56.

from the centre to the outside were observed on 1 in. round chill ingots, the outer portions being richer in copper. He was of the opinion that this phenomenon was caused by the chilling effect of the mould on the outer portions of the ingot, whereby a considerable amount of local undercooling might be induced. Many alloys were known to show this phenomenon of undercooling, some to a very marked degree. It was quite possible for alloys to undercool through several transformation points to below the eutectic point without undergoing any solidification, and he had observed this phenomenon on a number of occasions. Consider the condition of an alloy which had undercooled to a temperature below its eutectic point. It was possible for a *solid* constituent of eutectic composition to separate from this liquid simultaneously with, or even before, solids of higher melting point, since all stable alloys of the system could exist in the solid state at that temperature. He did not wish to do more than suggest this explanation as being more likely to be correct than that offered in the paper, but he had a certain amount of experimental evidence which bore it out, which however could not yet be published.

Dr. Smith, replying to the written discussion, wrote that he welcomed the criticisms which had been offered, and the many points of interest which had been raised. He wished to thank those gentlemen who had contributed. They had spared time and thought for considerations which, under the present circumstances, were clearly of less urgency than others upon which they were engaged.

Before attempting to meet in detail some of the points which had been brought forward, he ventured to recall the remarks made at the commencement of the paper (p. 66) with regard to the ultimate aim which he had in view, namely, to utilize the method of determining the surface tensions of molten metals and alloys, in order to afford evidence of molecular influences which are operative before solidification occurs. By this means it was thought the study of cohesion might be approached quantitatively from the known values of fundamental physical constants.

With regard to Mr. Greenwood's remarks as to the danger of students attaching undue importance to somewhat nebulous hypotheses (with which all exploratory work must necessarily abound), the author thought that in the present instance those remarks would in themselves serve as sufficient warning, if such warning were really necessary.

No one was more conscious than himself of the perplexities likely to be caused to students by attending or reading discussions on matters which were still inchoate, and he had recently given expression to feelings of concern on this point at another Institution.

The principle implied by Mr. Greenwood, however, of keeping to the well-beaten track lest students should be misled, was fortunately

one which had never received general sanction. It was clearly the duty of those who directed studies to guard students against attaching undue importance to exploratory excursions until their acquirement of ascertained fact was sufficiently complete to enable them to discriminate.

With regard to the relations of iron and carbon, it was felt that the pages of this Journal could not be appropriated to a discussion of views as to the constitution of steel, or to an attempt to support a modification of those views.

The coincidence afforded by the figures given on p. 94 was thought, however, to be of sufficient interest to be included in the paper. For the present, the author was content to leave the matter at that without indulging in speculation as to the significance.

With regard to the possible connection between the intrinsic pressures of compounds and those of their components, the work of Richards and the Harvard School on the volume changes accompanying the formation of metallic chlorides and hydroxides certainly pointed very clearly to the possibility of definite relations being established. The extensive work on volume changes in homologous series by Holmes and Sageman also pointed in the same direction.

Mr. Greenwood's difficulty, as to maximum hardness in the " stable state " not being attained at the eutectoid composition, lay in the fact that the maximum hardness in this case was exhibited by a heterogeneous mixture of two constituents—cementite and pearlite.

He was glad that mention had been made of the work of Benedicks,[*] to whom belonged the credit of having first introduced the idea that differing internal pressures in solid solutions accounted for differing degrees of cohesion as exhibited by hardness.

Mr. Greenwood's finding that the application of certain calculations (made by Benedicks and by Traube for carbon and γ-iron) to the somewhat doubtfully analogous case of Cu_3Al in copper did not appear to be warranted, hardly touched the present discussion.

The fact of a solid solution increasing in hardness as the percentage of the added element increased, while there was a corresponding increase in specific volume, had been dealt with in the case of the γ-alloys of copper and zinc on p. 97. These hard alloys were clearly of greater specific volume than alloys containing less zinc. The point to be ascertained, however, was whether careful determinations of density would not show that they were denser than would be demanded by the calculated density of the unalloyed constituents at this particular composition. The idea of " molecular rapprochement " would stand or fall by such density determinations.

Mr. Greenwood's alternative speculations regarding volume changes accompanying permanent deformation were very interesting and would

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[*] Benedicks, *Zeitschrift für physikalische Chemie*, 1901, vol. xxxvi. p. 5.

be of importance to metallurgists if substantiated. His view, however, of the possibility of " internal flaws " in cold-drawn wires being removed by short annealing, unless supported by direct evidence, was not convincing.

The author's experience indicated to him that such flaws might be thus accentuated rather than removed.

That the work of Kahlbaum on cold-drawn platinum was the " best example of this " was a statement which the author was strongly disposed to challenge. A scrutiny of this particular piece of work showed that inferences had been drawn from density determinations in which the actual change in volume of the water displaced could not have amounted to more than 3/10,000ths of a c.c.—an amount which was so small as to lay the determination open to grave objections.

The last point raised by Mr. Greenwood as to the position of aluminium in the relationship between intrinsic pressure and surface tension was one which must await repetition of the experimental work. The character of the surface of molten aluminium presented difficulties in effecting an entry into capillary tubes, although when this had been done the depth of the depression was found to be consistent, within narrow limits, as would be shown by reference to the original paper. Determinations were, however, only made in tubes of the largest diameter used. A still larger tube would be necessary to obtain other determinations which might be checked against those already recorded.

Sir Robert Hadfield had raised the question of the meaning which should be attributed to the term " cohesion," when considered in relation to the ordinary mechanical tests. The discussions which had arisen from time to time as to a definition of hardness had brought out very clearly the difficulties of associating it directly with either of the well-known attributes of materials.

Dr. Bengough had pointed out, in his admirable analysis * of the different measures of hardness, the necessity for avoiding any tacit deduction as to penetration hardness from tensile tests alone. This measure of hardness, referred to as " true penetration " or " mineralogical " hardness, appeared to conform most closely to the conception of molecular cohesion, and Bengough had suggested that the test which came nearest to determining this cohesion was that of the sclerometer devised by Turner.

Maximum cohesion, regarded in this way, was seen to be more or less synonymous with hardness which, considered industrially, might be spoken of as " brittle hardness." This hardness was generally useless, at any rate in all cases where high tensile strength was required.

With regard to the position of cobalt in the table given on p. 78, it appeared, from figures given in Traube's earlier work in 1903, that

* *Journal of the Iron and Steel Institute*, 1909, No. I. p. 426.

it would occupy a position of higher internal pressure than nickel. If this be accepted, then it would follow that its compressibility should be less than that of nickel and its hardness greater.

The question of the applicability of the methods indicated in the paper to the cases of alloy steels, was one to which the author had directed some attention before the publication of the paper. He concluded that such application ought not to be beyond the possibilities of experimental methods, but as speculation at this stage could, from the nature of things, have little or no real value until an opportunity arose for further experimental work, it would seem undesirable to make further comments. The matter was, of course, of the greatest interest and importance.

With regard to Mr. Hanson's remarks on the continuity of properties, he rightly pointed out that a considerable amount of caution should be adopted in assuming any continuity in the liquid and solid states. Certain properties were undoubtedly continuous in the two states, and something of value would be gained if it should be found possible to trace a quantitative relation between the surface tension in the molten state—admittedly a measure of the molecular cohesion in that state—and some property dependent on cohesion in the solid state.

The author was disposed to agree with Mr. Hanson that " determinations of the elastic limit would seem to offer much more reliable data for determining the molecular cohesion of metals " than the tensile test. The remarks of Bengough, already referred to, had a direct bearing on this point.

With regard to the question of liquation, Mr. Hanson's reading of the Le Chatelier principle of " mobile equilibrium " evidently differed from that of the author. The important point, however, was that the facts regarding this particular behaviour of alloys, so strangely neglected by modern workers, should be correctly observed and stated, and that its occurrence should no longer be overlooked in relation to uniformity in composition in material other than gold and silver bullion, in which alone its effects had so far been carefully observed and guarded against.

It was interesting, in this connection, to find that Mr. Hanson had himself observed such wide variations in alloys of aluminium and copper within such narrow limits of composition. His alternative explanation, however, that these variations in composition were due to local undercooling on the outer portions of the ingot did not appear to be convincing. He would find that the conditions under which undercooling or " surfusion " had been studied by Riemsdijk, Roberts-Austen, Heycock and others, differed very materially from those which obtained when metal was poured into a chill mould.

The adjustments of composition to a falling temperature which had been suggested in the paper as the explanation of the variations in composition could only occur while the metal was still molten.

Once the solidification began, the general macroscopic composition —apart from possible slight variations from grain to grain—was, of course, fixed. Even under perfectly tranquil conditions, when surfusion was possible, this solidification occurred with startling suddenness, as shown by the work of those whose names had been mentioned, and in particular, perhaps, that of Heycock on certain alloys of gold and aluminium.

THE ANNEALING OF NICKEL-SILVER.*
(PART II.)

By F. C. THOMPSON, D.Met., B.Sc. (Demonstrator in Metallography in the University of Sheffield).

THE first part of the investigation of the annealing of nickel-silver, already published in the Journal of the Institute,† dealt fairly fully with the influence of the temperature of annealing on the physical properties of hard-drawn or rolled alloys of varying composition. The results obtained showed clearly in several cases the influence of the transition first discovered by Le Chatelier which occurs in all these alloys, at about 300° to 400° C. The present communication deals chiefly with the effect of the duration of annealing at a definite temperature, and with some further observations regarding the change at 300° C. which bear upon the influence of the rate of cooling from the annealing temperature.

All the work planned by the author in connection with the influence of the temperature of annealing has not yet been carried out—in particular no tensile tests or micrographs have as yet been published. The results are recorded of a very considerable number of tests made on an alloy containing approximately 60 per cent. of copper and 10 per cent. of nickel, which had been cast, rolled, and annealed for varying periods, but at the same temperature under actual works conditions. The author is deeply indebted to Messrs. The Heeley Silver Rolling and Wire Mills, Ltd., at whose works the preliminary treatment was given, and specially to Mr. Reynolds and his assistant, Mr. Gadsby. It has also been possible to investigate some other points of considerable practical importance.

INFLUENCE OF THE DURATION OF ANNEALING UPON THE PROPERTIES OF THE METAL.

For these and other experiments, four ingots of nickel-silver were cast of as nearly as possible the same composition. Of

these, two were melted in " black-lead " pots, and two in clay
crucibles. Further, of each pair one was untreated, while the
other was deoxidized with manganese, as cupro-manganese, for the
purpose of obtaining further evidence with regard to the effect of
such treatment, in view of the results obtained by Drs. Hutton
and Greenwood,* which are at variance with those of the author
already recorded.

The materials used were 80/20 cupro-nickel scrap, made up
to composition with virgin copper and zinc. During melting no
flux was used, but a layer of charcoal was maintained on the
surface of the metal. The deoxidation was carried out by the
addition of 0·25 per cent. of 70/30 cupro-manganese 5 to 10
minutes before casting. All four casts were made under as far as
possible absolutely identical conditions, and by the same melter.

The analyses of the four ingots which have been made for the
author by Mr. H. Gadsby are recorded in Table I.

TABLE I.—*Chemical Composition of Ingots.*

| | Melted in " Black-lead " Crucibles. | | Melted in Clay Crucibles. | |
	Untreated.	Deoxidized with Manganese.	Untreated.	Deoxidized with Manganese.
Ingot Nos. . . .	1.	2.	3.	4.
Copper . . .	61·96	60·62	61·23	61·67
Zinc . . .	27·56	29·40	27·90	27·72
Nickel . . .	10·18	9·70	10·45	10·25
Iron . . .	0·21	0·17	0·30	0·24
Lead . . .	trace	trace	trace	0·09
Manganese . . .	nil	nil	nil	trace
Silicon . . .	nil	nil	nil	nil
Total . . .	99·91	99·89	99·88	99·97

After the ingots had been rolled down to ⅛-in. thick, specimens
6 in. by ⅜ in. were cut, both lengthwise and transversely, from
the hard-rolled, unannealed strips. These were close-annealed in
iron pots in duplicate at a temperature of about 800° C. ± about
10° C., which was controlled by a thermo-electric pyrometer,

projecting through the roof of the muffle. All the samples were prepared entirely under ordinary works conditions at the Heeley Silver Mills, and hence are specially valuable in affording a practical check upon the conclusions arrived at in Part I., from tests carried out on materials prepared in the laboratories of the University. As will be seen from the results here to be recorded, the agreement leaves nothing to be desired between the works and laboratory tests. The times of annealing given are those for which the strips were at the maximum temperature, measured from the time at which that was attained until cooling down commenced.

Each of the strips was then tested at each end in the Arnold alternating-stress testing machine, under the specially severe conditions previously specified, and the Brinell hardness was determined under a load of 500 kilos with a 10 mm. ball.

No measurements of the tensile properties of the strips have been made since, as it is well known, the tensile strength of an annealed strip of such an alloy is practically unaffected by wide variation of the duration and temperature of annealing under practical conditions. Changes in the true elastic limit, however, probably do occur, but for such determinations a delicate extensometer would be required. Such an instrument, which could be attached to thin strips, was not at the author's disposal. Further, the experience already gained in the testing of this nickel-silver has satisfied the author that alternating-stress tests involving, as they do, in the Arnold machine, a certain amount of plastic deformation, would yield all the information required. Valuable as this method of testing has proved itself to be in the examination of steels, it is no less so in the region of the non-ferrous metals, and the tests already recorded in the earlier paper bear evidence in its favour. The practically unchanged value of the Brinell hardness number (Table III.) confirms the statement that the tensile strength is a poor criterion with regard to the efficiency of annealing of the nickel-silvers. There is, as is now well known, a definite relationship between the hardness and the maximum stress, whence an unchanged hardness figure is equivalent to an unchanged tensile strength. Especially in determining at what point an efficient annealing gives place to over-annealing, the tensile strength is distinctly inferior to alternating stress tests.

The results of these tests are recorded in Tables II. and III.

TABLE II.—*Alternating-Stress* (*Arnold*) *Test Results.*

Time of Annealing.	Temp. °C.	Ingot No. 1.		Ingot No. 2.		Ingot No. 3.		Ingot No. 4.		Grand Mean.
		Longitudinal.	Transverse.	Longitudinal.	Transverse.	Longitudinal.	Transverse.	Longitudinal.	Transverse.	
1 hour	760	610	646	660	632	787	636	654	924	693
2 hours	800	684	898	760	1052	1132	1023	782	1195	841
3 ,,	800	756	991	814	1063	797	901	880	1054	907
4 ,,	840	784	873	864	975	905	944	922	1196	933
6 ,,	800	807	1221	760	1070	802	946	802	1045	932
7 ,,	800	725	932	681	970	781	852	691	1072	838
Mean		727	927	756	960	860	884	792	1081	
Grand mean of all tests on each ingot		827		858		872		936		

It should be mentioned that each figure inserted in the ordinary lists of Table II. is the mean of four tests—*i.e.* one on each end of the duplicate samples. The grand means, therefore, of all the tests made on all the strips annealed for the same period of time are obtained from no less than 32 separate determinations, and hence are worthy of the greatest confidence. Similarly, the grand means of the results obtained from each ingot are of 48 tests, 24 on strips cut longitudinally and 24 cut transversely.

There are several interesting conclusions which may be drawn from these results. Considering, in the first place, the influence of the duration of annealing upon the number of alternations which the metal will endure, it will be seen that this rises steadily from 693 after one hour's annealing to 933 after four hours'. Practically the same result is obtained from the metal heated for six hours, but the results after seven hours are consistently and distinctly poorer, the metal being more brittle and less ductile, the number of alternations endured having dropped to 838. These results have been plotted in Fig. 1, from which it will be seen that under the conditions under which these annealings were carried out—*i.e.* close-annealed at 800° C.—a period of annealing of five hours will yield metal in its most ductile condition. It is the practice in certain works, especially during the night, to leave the pots in the annealing oven for as much as twelve hours—a procedure which, as these results show, is as unsatisfactory metallurgically as it is wasteful economically. It is, however, rarely that the extreme degree of ductility is required, and for many purposes, such as ordinary stampings, a considerably shorter period of heating yields quite satisfactory results.

The second point of interest arises from the marked superiority under alternating stress of the metal melted in clay crucibles over that melted in " black-lead " pots. The improvement is shown in both the untreated and deoxidized ingots, the mean of all the tests made on the metal from the clay pots being 904, that from the " black-lead " crucibles being only 842. To the author this result was unexpected, since the liability of the metal to oxidation during melting would appear to be greater in the case of the clay crucibles than in that of the others. On further consideration, it appeared that the improvement might conceivably be due to a deoxidation by silicon reduced and dissolved

into the metal from the walls of the pot, a reaction which un-
doubtedly occurs in the melting of steel by this process, especially
in the case of charges high in manganese.   The analyses of Table I.
show that none of the ingots contains silicon ; but this fact does
not disprove the hypothesis put forward above, since that element
may combine with oxygen present in the melt, and pass into the
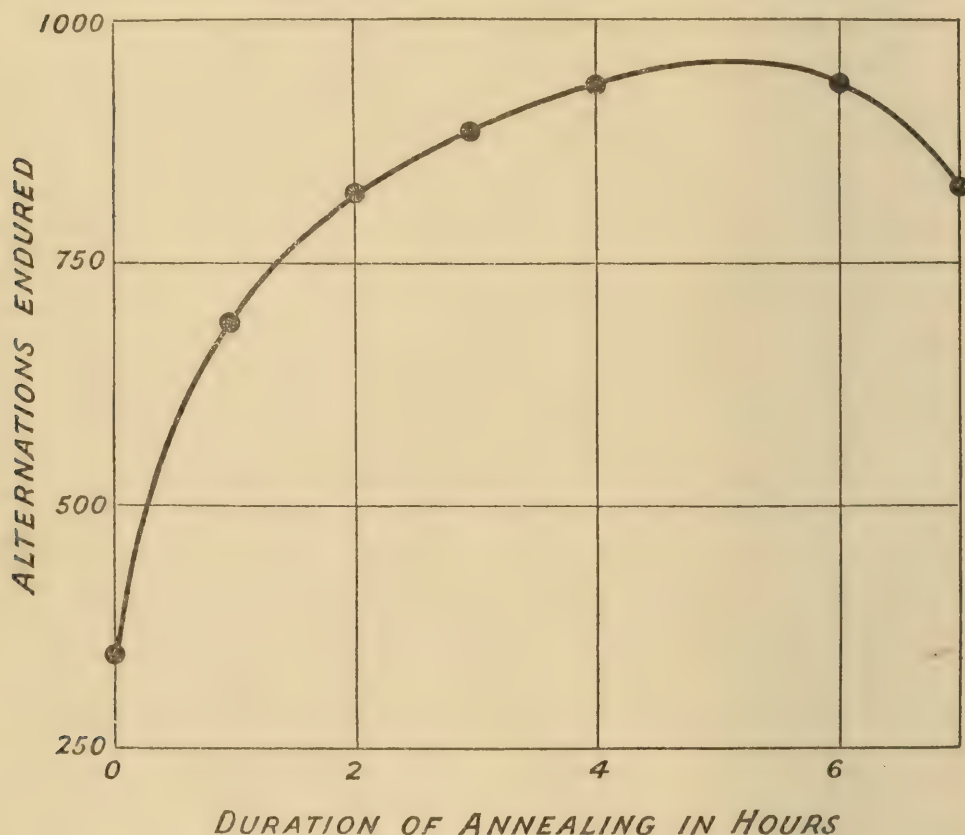
Fig. 1.

slag as fast as it is reduced.   It is of interest in this connection
that the strips cut from the metal melted in clay pots which has
been treated with manganese shows a distinctly greater improve-
ment over those from the untreated alloy than does the metal
from the black-lead crucibles.

A comparison of the results given by the strips cut longitudin-
ally with those cut transversely shows clearly the marked superio-
rity of the latter.   This is entirely opposed to the results obtained
on other metals, in which the number of alternations endured
by a sample cut longitudinally is consistently greater than that

recorded by one cut across the direction of rolling. The explanation of the fact is not easy to see, but it does not appear to be a point of much practical importance, though it will be borne in mind in future work.

The results in Table II. are further of value in the light which they throw upon the improvement or otherwise which arises from deoxidizing the molten metal with manganese. So far as these tests go, the samples cut from the deoxidized ingots are distinctly superior to those from the untreated. The mean of the forty-eight results of samples of untreated metal is 850 alternations, while that of the same number from deoxidized casts is 897, an improvement of 5½ per cent. This result obtained from samples of metal prepared under the ordinary conditions of works practice entirely confirms the conclusion already arrived at from tests on laboratory samples—that deoxidation of nickel-silver with manganese does improve the ductility and toughness of the alloy. As will be seen from Table III., this treatment exerts practically no influence on the hardness of these samples. In their communicated discussion to the author's earlier paper, Drs. Greenwood and Hutton remarked, " The addition of a deoxidant, where any such remained in the metal, was invariably found to have the effect of raising the tensile strength and hardness, while lowering the ductility in the rolled and annealed condition." With regard to this, the author is in entire agreement. In the author's earlier results of the twelve analyses made upon nickel-silvers to which less than 0·25 per cent. of manganese had been added, none shows more than a " trace " remaining. The analyses had been made by two different and expert analysts on materials of very different origin, five being exceedingly pure alloys, prepared under laboratory conditions ; the other seven being cast in the ordinary run of works practice, and at two perfectly independent establishments. In all the author's tests the deoxidized material was sounder, rolled better, was, when in the same condition, of greater electrical conductivity, softer, tougher, and more ductile than were the untreated samples. The whole point of difference, however, lies in the fact that in these cases none of the deoxidant had remained in the metal, which is the ideal to be aimed at. On the other hand, Drs. Greenwood and Hutton admit excess manganese was present in their own samples, to which fact, in the author's opinion,

is due the unsatisfactory results which they obtained from the
use of that metal as a deoxidant.

When the results of these alternating tests are compared with
those already recorded in Part I., it will be seen that the tempera-
ture chosen—800° C.—was slightly above that which gave the
highest endurance in the earlier series. The present samples, how-
ever, show a very great improvement over those of the previous
set. Thus the alternations endured by alloy " 11 " (after being
annealed at 785° C.), the composition of which is practically
identical with that of ingot " 4," was only 326 against about 1000
sustained by " 4." The explanation of the difference appears to
lie in the longer soaking received by the specimens examined in
the present paper, and in the considerably slower cooling, a
point which will be further considered at some length later.

Turning our attention now to Table III., in which the values of
the Brinell hardness numbers are collected, little need be said.

<div align="center">TABLE III.—<i>Brinell Hardness.</i></div>

Duration of Annealing.	Temp. °C.	Melted in " Black-lead " Crucibles.		Melted in Clay Crucibles.		Mean.
		Untreated.	Deoxidized.	Untreated.	Deoxidized.	
		1.	2.	3.	4.	
1 hour	760	50·5	49	50·5	51	50
2 hours	800	48	48	48·5	50	48·5
3 ,,	800	45·5	48	47·5	46	47
4 ,,	840	45	45	45·5	43	44·5
6 ,,	800	49·5	46	47	45	47
7 ,,	800	42·5	45	48·5	48	46
Mean .	...	47	47	48	47	...

The strips annealed for three or more hours are *slightly* softer than
those annealed for a shorter period, the extra softness of the
samples annealed for four hours being probably due to the slightly
higher temperature then employed. So far as the mean hardness
goes no difference can be detected between metals melted in clay
or " black-lead " crucibles, between those untreated and those
deoxidized, or between samples cut longitudinally or transversely.
In Table III. the means of the latter are recorded.

INFLUENCE OF THE RATE OF COOLING ON THE PROPERTIES OF THE ALLOYS.

In annealing metals and alloys in which no abrupt transition point or phase-change occurs, the rate of cooling thereafter is of comparatively little moment in determining the properties of the finished material. In the case, however, of such an alloy as nickel-silver in which, as was abundantly shown in Part I., there exists a distinct transition, about 300° to 400° C., the velocity with which the hot metal is cooled down to room temperature, and especially that in the neighbourhood of the change and just below it, may exercise a profound influence on the constitution and properties of the resultant metal.

The samples, of which tests have been already recorded in this paper, which had been close-annealed had been cooled very slowly in the pots, though unfortunately at an unknown rate. The specimens which had been tested for the earlier paper had received a " normalizing " treatment, being cooled separately in air and therefore, in the case of such thin strips, fairly rapidly. It was decided to complete the series by quenching another set as rapidly as possible in cold water, from temperatures above the change point after a previous heating to 720° C., to remove any traces of cold work and to bring them all to a uniform condition. The materials used were samples of the five commercial alloys containing from 10 to 23 per cent. of nickel, the complete analyses of which were given in the earlier paper.* Three series of quenchings were carried out—one set of samples being quenched at 370° C. after being heated to 720° C., and then slowly cooled to the quenching temperature. The second set was quenched at 510° C. after a similar previous treatment, while the third was quenched directly from 720° C. The heatings were carried out in a gas-fired muffle, the pieces having the same dimensions—*i.e.* 6 in. by $\frac{3}{8}$ in. by $\frac{1}{8}$ in.—as before, except in the case of " 9," which was much thinner, the alternating-stress results on which are therefore not directly comparable with those on the samples of the other compositions. On each sample alternating-stress tests were made in duplicate in the Arnold machine, and the Brinell hardness measured. The results are collected in Tables IV. and V.

TABLE IV.—*Alternating Stress Tests on Quenched Samples.*

Treatment.	Mark	9.	11.	14.	20.	25.
	Ni content	9·9	10·6	12·2	18·8	23·1
Annealed at 720° C. and air cooled		1337	343	348	252	192
Quenched at 720° C. . .		1443	444	682	344	175
,, ,, 510° C. . .		1321	472	617	332	180
,, ,, 370° C. . .		1280	427	524	372	215

TABLE V.—*Brinell Hardness of Quenched Samples.*

Treatment.	Mark	9.	11.	14.	20.	25.
	Ni content	9·9	10·6	12·2	18·8	23·1
Annealed at 720° C. and air cooled		65	63	70	74	80
Quenched at 720° C. . .		58	53	55	61	74
,, ,, 510° C. . .		62	57	59	69	77
,, ,, 370° C. . .		57	55	56	72	79

In Tables IV. and V. have been included, for purposes of comparison, the corresponding values for the samples annealed at 720° C. and then cooled in air. The results show that the quenched samples are consistently softer and more ductile than those air cooled—normalized. In respect both of hardness and of endurance to alternating stress, the alloy with 12·2 per cent. of nickel shows the greatest improvement, which is interesting, since this is the alloy in which is present the greatest amount of the compound NiZn$_3$, to which the cause of the change was tentatively ascribed.

The results obtained on the quenched specimens are, however, not so good as those yielded by those close annealed and very slowly cooled, so that it would not appear in the present state of our knowledge that quenching possesses any commercial possibilities.

In Part I. were recorded a few tests made on the same series of alloys when annealed at 930° C., and either air cooled or slowly cooled in the muffle. To facilitate reference the pertinent values are reproduced in Tables VI. and VII.

TABLE VI.—*Alternating Stress Tests on Alloys annealed at 930° C.*

Treatment.	Alternations Endured.				
	9.	11.	14.	20.	25.
Cooled in air . . .	1023	170	255	262	73
Cooled slowly in muffle . .	1431	362	360	260	...

From this table it will be seen that *slow* cooling from the same temperature increases the resistance of the alloys to alternating stress ; but, as we have seen, *so does very rapid cooling—quenching.* A second unexpected result is obtained from the figures in Table VII., from which it will be seen that *those alloys more slowly cooled are harder than those cooled rapidly.*

TABLE VII.—*Brinell Hardness of Alloys annealed at 930° C.*

Treatment.	Hardness Number.				
	9.	11.	14.	20.	25.
Cooled in air . . .	50	55	61	57	70
Cooled slowly in muffle . .	65	65	65	70	114

Such paradoxical results confirm abundantly the statement of Drs. Hutton and Greenwood, that " experience with the manufacture and use of the nickel-silver alloys left the impression that they are delicately balanced in constitution and liable to serious modification in properties by small amounts of certain impurities or unsuitable mechanical or thermal treatment."

To afford some explanation of the foregoing and similar results the author desires to put forward, at any rate tentatively, the following.

When Le Chatelier first announced his discovery of the change in these alloys, he stated that one of its peculiarities was the slowness with which it proceeded. Robin, however, showed that the velocity was not so small, but that the transition did proceed, in part at any rate, with even moderately quick rates of heating and cooling. Now, considering a sample annealed at, say, 700° C. for a sufficient length of time to be in equilibrium at that temperature, it may be supposed to consist entirely of phase A. When the sample is cooled down to the transition temperature it will, provided the rate of cooling be sufficiently slow, change completely into the modification B stable at low temperatures. If, however, the rate of cooling be accelerated, and sufficient time be not allowed for the change from A to B—which is rather a slow one when compared, for instance, with the changes which occur in iron and carbon steels—to complete itself, the material may be expected to consist at room temperatures of both phases A and B in amounts determined by, amongst other factors, the velocity of cooling. If, however, finally, as a result of some quenching process, the cooling of the alloy be excessively rapid, it may be considered to consist more or less completely of modification A in the meta-stable form. Such an alloy, therefore, as the nickel-silvers, may, broadly speaking, consist, according to the thermal treatment to which it has been subjected, of pure A, pure B, or—and this will be by far the most common—a mixture of both A and B, and according to the constitution, so will the mechanical properties vary. The tests already recorded enable some idea

TABLE VIII.—*Influence of Rate of Cooling upon the Properties of an Alloy containing 10 per Cent. of Nickel.*

Treatment. No.	Treatment.	Alternations Endured.	Hardness.	Suggested Constitution.
1	Cooled very slowly in large closed pot from 800° C.	932	47	B
2	Cooled in thin strips in air from 720° C. .	343	63	B+A
3	Quenches in water from 370° C. . . .	427	55	A+little B
4	Quenched in water from 720° C. . . .	444	53	A

B is low temperature form.   A is high temperature form.

to be gained of the properties of the same alloy in the different
states, and show that samples which consist entirely, or almost so,
of A or of B are soft and ductile, while those in which both A and
B are present are *relatively* harder and brittle. In Table VIII.
are collected the results obtained from the alloy containing about
10 per cent. of nickel and 61 per cent. of copper, in which the rates
of cooling from a red heat have been varied within wide limits.
It will at once be seen that the samples cooled very slowly or very
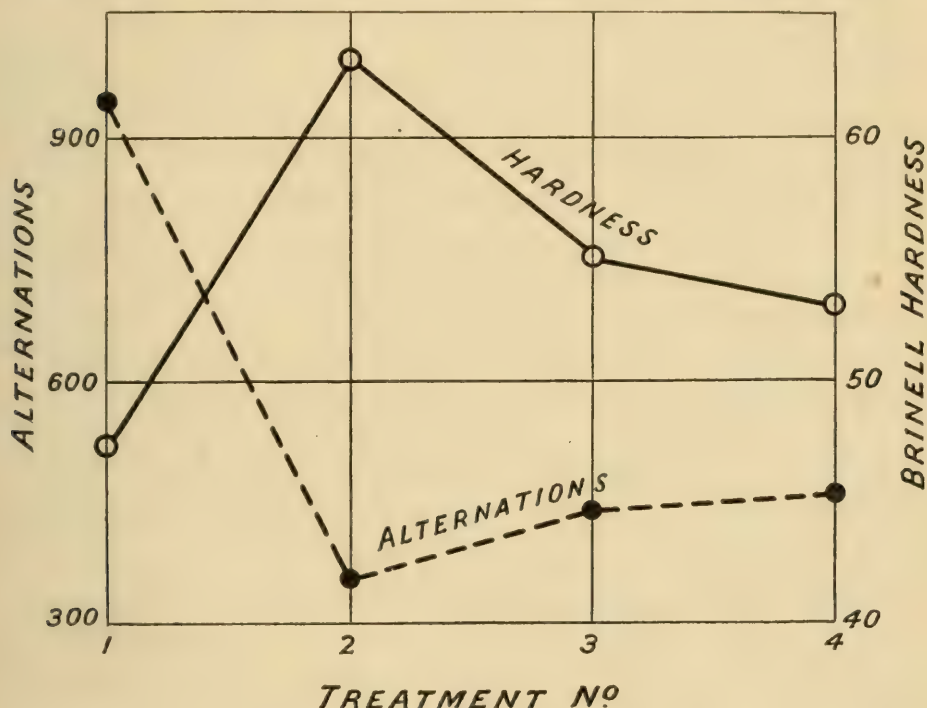
Fig. 2.

quickly are the most ductile and the softest, while the others be-
come harder and less tough. The results are shown graphically
in Fig. 2.

A more elaborate series of tests was carried out in which the
strips were cooled at twelve different rates, but the results were
irregular. The heating up of the specimens, however, was carried
out very quickly, and insufficient time was allowed for the change
on heating to take place, the time of heating to the quenching tem-
perature of 700° C. being barely 15 minutes, after which the
strips were at once quenched. The following results, however,
are in agreement with those of Table VIII., and there appears to

be no reason to doubt that had sufficient time been allowed for the samples to attain the equilibrium condition at 700° C., complete confirmation of the foregoing hypothesis would have been found.   In the future it is hoped that time may be found for this series of tests to be repeated.

	Alternations.
Quenched in oil	727
Cooled in air	673
Cooled in open muffle	620
Cooled in closed muffle	637
Cooled very slowly in sand in closed muffle	730

The theory advanced is therefore consistent with all the results obtained, and it is of interest to find in it another similarity in the behaviour of these alloys to changes which occur in steel. To anyone familiar with the metallography of steel the parallelism will be at once apparent, and since the explanation proposed of the change of properties which may occur in the nickel-silvers is on all fours with the generally accepted theory for those in steel, it is the more readily credible.   The form B will then correspond to the fully annealed " pearlite steel," the A form to the " austenitic " form, while the mixture of both A and B will be the parallel of the ordinary hardened steel composed of " hardenite " or a troostitic or sorbitic form, according to the proportions present.   Why the intermediate form should be much harder and more brittle than the soft and ductile materials from which it is supposed to be due, cannot be definitely answered here, any more than it can be dogmatically asserted why " hardenite " should possess its characteristic properties.   An explanation to be satisfactory would have to fit both cases, and it is not impossible that work done on the more simply constituted nickel-silvers may throw valuable light upon the theory of the hardening of steel.

It has already been shown by the author that no heat change which can be practically determined accompany the transition from A to B, nor has he yet been able to detect any micrographic change.   These facts are to be expected, since Tafel had missed the transition entirely.   They have a certain amount of value in emphasizing the possibilities of error in metallographic examinations, in which the thermal properties and microstructure alone are considered.   Measurements of electric resistance afford an extremely valuable check on the foregoing.

The hypothesis of a phase-change about 300° C. to 350° C.

affords for the first time also an explanation of the neutral point observed in the thermo-electric properties of the alloys. Fig. 5 of the earlier paper gives a few of the curves obtained. In the curve for alloy 265 containing 16·3 per cent. of nickel, this neutral point occurs at 250° C., 225° C. below the annealing temperature of 475° C. If the alloys consist of a single unchanged phase these results are very difficult to explain, but if the high temperature constitution differs from the low one, and if the former is retained more or less by rapid cooling, the results find a fairly ready explanation. These curves were determined for a thermo-couple, consisting of a soft wire against a hard-drawn one of the same composition. It would appear that the influence of the cold work upon the transition is more or less profound, and other experiments in this direction will be undertaken as soon as the return to more normal conditions allows.

It is now possible to discuss, in the light of this theory, results obtained in Part I., which were then merely recorded without being understood. When the hard-drawn or rolled alloys were heated to the lower temperatures, well below that at which ordinary softening and recrystallization occur, it was found that they became gradually, but with increasing rapidity in the neighbourhood of 300° C., harder and less ductile. The measurements of the Brinell hardness, recorded in Tables VII., VIII., and X., and Fig. 7 of Part I., show this increase of hardness admirably, a corresponding rise in the electrical resistance being shown in Table V. and Fig. 1. The loss of ductility is evidenced by the torsion results in Table VI., but still better by those of the alternating-stress tests of Table XI. and Fig. 8. These results are exceptional, and would not have been expected. They have received confirmation from the remarks of Drs. Greenwood and Hutton in the discussion on the earlier Part I., where it is remarked that those " writers had some reason to believe that the resistance to alternating stress (Arnold) of ordinary mill annealed nickel-silver was slightly lowered by a short reheating to 400° C. and subsequent cooling."

When an alloy in a meta-stable state is reheated, there is a tendency for it to return to the stable condition. This tendency increases as the temperature is raised, and becomes a maximum at a temperature somewhat below that at which the change which

had been suppressed occurs. Now, if as a result of quick cooling the high temperature modification of a nickel-silver is retained, wholly or in part, the resultant alloy is at ordinary temperatures in such a meta-stable state. When it is heated to gradually increasing temperatures, the tendency for the change of the A into the B form increases, and ultimately, if sufficient time is allowed at a suitable temperature, generally slightly below that of the change, the inversion will be complete, and the stable B state reached. When, however, insufficient time is allowed for this to occur, the process of heating will have resulted merely in the conversion of part of the A into B, and as has already been shown such a mixed constitution is characterized by relatively hard and brittle properties.

Thus the increase of hardness and loss of ductility in those specimens heated to about 300° C. are explained, this at the same time lending additional evidence in favour of the theory proposed.

Some idea of the influence of time on this change—which by the way is strictly analogous to the " tempering " of a quenched steel —may be obtained from a comparison of the hardness results of Tables VII. and VIII. of the earlier paper : the specimens being maintained at the maximum temperature for 10 minutes and $1\frac{1}{4}$ hour respectively. The maximum hardness is reached in the case of the short annealings at a mean temperature of about 315° C. (which is apparently independent of the composition of the alloy), compared with 285° to 290° C. for the soaked specimens. In each case, however, the commencement of the sudden hardening occurs about 265° C., with the result that, when plotted, the peak in the hardness-temperature curve becomes much sharper for the specimens which have received the longer annealing. This is in complete accord with the suggestion that the change concerned is one from a meta-stable to the stable state, the time allowed enabling the change of $A \gg B$ to attain completion at a lower temperature once a certain minimum temperature, which is essentially unaffected by the rate of heating, is surpassed.

In conclusion, one point of more directly practical importance arising from these considerations may be mentioned. Where a large batch of sheets, &c., is annealed and then drawn and cooled in air, those which have chanced to be placed outside

will often undergo a far more rapid cooling than those in the centre of the heap. Articles thrown on damp and cold iron floor-plates, or those subject to the dripping of rain through leaky roofs, &c., will possess properties clearly different from those of other parts of the batch which have cooled more slowly. To obtain the desired uniformity of produce, some care appears to be necessary in this direction.

DISCUSSION.

Mr. F. Johnson, M.Sc. (Birmingham), in opening the discussion, desired first of all to congratulate the author on having described a research on a subject of which very little was heard at the meetings of the Institute. The subject, nevertheless, was a very important one, about which the members desired to obtain a great deal more information. He ventured to suggest that it would have been of great value if the author had carried out static tensile tests, not as much from the point of view of obtaining the ultimate tensile stress of the nickel-silvers, as of correlating the ductility measured by elongation with the results of the Arnold test. The author had pointed out that he obtained a better result by melting in clay pots than by melting in plumbago pots. He suggested for the author's consideration that there was a possibility that carbon might have been absorbed by the nickel-silver when the melting was done in the plumbago pots, and that perhaps would have an adverse influence on the result. The author had referred to the comparative inferiority of the metal in the Arnold bending test when the longitudinal strips were tested, an inferiority which was contrary to experience with other metals. In the present case superiority was obtained in the transverse specimen. In that case he suggested that lamination was present due to coring, the laminæ being produced by the rolling process, and the more ductile laminæ accommodating themselves to the bending stresses, to a greater extent than the harder laminæ.

Dr. O. F. Hudson (London) said that the author in his very interesting paper had recorded the results of a large amount of work. It was perhaps, therefore, ungracious of him to suggest that the accumulation of further data was necessary before all the author's conclusions could be accepted. First of all, with regard to the question of the possible polymorphic change that occurred in nickel-silver, the author referred to it as being analogous to the changes that occurred in steel during hardening, but it did not seem, on the evidence to be found in the paper, that the analogy was very clear. It was true that there were changes in the properties of the slowly cooled and in the quenched nickel silver, but there did not seem to be at present any experimental proof that the change was in any way similar to that which occurred in steel. He did not know if the author would suggest that in the case of nickel-silver there was a breaking up of the high temperature form into two other phases at a lower temperature, as happened in the case of the steel. The principal mechanical tests given in the paper were the Arnold test and the Brinell hardness test. He agreed with Mr. Johnson

that it would be of very great interest if the tensile tests were also given, in order that a comparison might be made. He noted that the Arnold test figures on which the author's conclusions were based were the means of the results of a large number of tests. These figures, however, seemed to him to be open to some criticism, as the tests included in the table showed extremely wide variations, far beyond those on which the curve given in the paper were based. He desired to ask the author if the individual tests were concordant. Either there were unlooked-for variations in the metal itself, or the test was capable of giving varying results. For example, one sample of the first alloy had a test number of 1221, and the average figure was 927. Such variations were very great, and it seemed to him that an endeavour should be made in some way to account for them before any very definite conclusions were drawn from the mean results. Possibly some of the variations might be due to small differences in heat treatment. He noticed that in the determination of the temperature of heat treatment it was stated that the temperatures varied by about $\pm$ 10°. When dealing with rather critical work of that kind, it appeared to him that the annealing temperatures might be controlled to rather a greater degree of closeness than that figure. Possibly some of the variations in the test results might be due to unexpected variations in the annealing conditions.

COMMUNICATIONS.

Dr. H. C. GREENWOOD and Dr. R. S. HUTTON (Sheffield) wrote that, in their opinion, it was not advisable to accept as a satisfactory conclusion of the matter Dr. Thompson's remarks on deoxidation. The whole question of "deoxidizing" additions was one of great practical importance in metal casting, and it was hoped would in the near future form the subject of communications to the Institute. They would point out that the author's addition of 1·5 and 0·25 per cent. manganese in the earlier paper, and 0·25 per cent. 70/30 cupro-manganese in the second paper, in all cases resulting in nothing more than a "trace" of remaining manganese, are quite contrary to their own results.

Moreover, they would remark that if the cupro-nickel scrap employed was of ordinary munitions standard its content of manganese would be quite appreciable, and the classification of one lot of the metal as "untreated," therefore misleading.

If the alloy were so oxidized as to need 1·50 per cent. manganese or more, it surely must have been insufficiently deoxidized by 0·25 per cent., for after all the reaction was a fairly sharp one, and its completion could only be determined by a small quantitative excess of manganese

remaining. The author admitted that the ideal to be arrived at was that none of the manganese should remain, and also stated that the use of manganese improved the alloy. They presumed that his ideal might more exactly be stated to be an addition of just the amount of manganese necessary to completely deoxidize the alloy.

If the condition of the alloy were such as to need a large quantity of deoxidant, there was always the risk that the products of its action might remain entangled in the alloy, and it was on such considerations that they held the view that the best results with nickel-silver were obtained by melting materials, of the purest quality obtainable, in such a way as to minimize as far as possible oxidation, rather than by doctoring up a less pure or oxidized mixture.

In any case, greater exactitude in the use of the deoxidant should readily be obtainable in general practice.

With regard to the comparison of strips cut longitudinally and transversely to the direction of rolling, they had records of nickel-silver alloys containing 12, 15, 18, and 22 per cent. nickel, all giving results of the tensile strength rather lower and elongation distinctly higher for the transverse strips. This comparison was made with the precaution of omitting the usual passing of the broken-down ingot crosswise through the rolls, and the results seemed to give an interesting confirmation of the author's observations—moreover, in certain special processes of manufacture this property was a distinct advantage.

Although the variation of breaking stress and elongation with composition and annealing was somewhat small it was nevertheless reliable, and in the writers' opinion, however valuable the alternating stress measurements might be in a special research of this nature, the fact that large and often unaccountable fluctuations occurred, as evidenced by the author himself, rendered it much less suitable for estimating the working quality of a series of alloys prepared under widely different conditions.

Dr. THOMPSON, in reply to the discussion at the meeting, wrote that he was much indebted to Mr. Johnson and Dr. Hudson for their contributions. Despite the criticism which had been passed upon the paper on account of the mode of testing adopted, he (the author) was still firmly convinced that for the special purpose in view, viz. the determination of the period of time which first caused a metal of definite composition, annealed at a definite temperature, to show signs of over-annealing, tensile tests, unless measurements of the *true* elastic limit were taken, were of very little value. Not until the over-heating had reached a very definite stage did even the elongation show any decided fall. The Arnold tests would demonstrate a deterioration considerably earlier. Charpy also had emphasized the insensitiveness of the tensile test from this point of view.

Dr. Hudson's criticisms were many. In the first place, he spoke of a " possible " polymorphic change. If a sudden change in electric

conductivity on heating, a sudden drastic alteration of acoustic properties (both shown independently of the author), a sudden change in the hardness of the reheated alloy—an *increase* of hardness, moreover, which occurred at a temperature 200° C. below the annealing temperature—combined with a decrease of ductility, as evidenced by alternating-stress and torsion tests—if all these were not evidences of a change of a polymorphic nature, the author could only ask Dr. Hudson what conceivable alternative explanation there was ! Further, Dr. Hudson had pushed the analogy between this change and that which occurred in carbon steels a very great deal too far. He even asked " if the author would suggest that in the case of nickel-silver there was a breaking up of the high temperature form into two other phases at a low temperature," whereas, if he had read the paper at all thoroughly, he would have found that the author had distinctly stated that, so far, no micrographic change accompanying the transformation had been detected. Dr. Hudson also did not seem to have realized the fact stated on p.121, that these annealings had been carried out in *works* annealing muffles according to ordinary works practice. If he had, he would hardly have made the statement that " the annealing temperatures might be controlled to rather a greater degree of closeness than $\pm 10°$ C." To maintain a 20-ft. furnace to within 10° C. for seven hours was a most excellent piece of work, and the author saw no reason whatever to believe for an instant that such a variation in temperature, far away from any critical changes, would produce any appreciable effect upon the mechanical or other physical properties of the metal. The variations in the alternations endured, concerning which Dr. Hudson had so much to say, were no more than would be found in any special test such as this one, or a shock or impact test, but it was for that reason that the curve, Fig. 1, had been drawn from figures which were the mean of a very large number of tests. That the variation in the individual results should be greater than those of the curve therefore—a fact which seemed so surprising to Dr. Hudson—would be readily understood by anyone who had made a series of physical measurements of the same quantity, taking the mean to obtain a more accurate result. Dr. Hudson complained that one alloy had given a test of 1221 when annealed for six hours—practically the ideal length of time—while the mean of the tests on all the samples of this particular alloy gave but 927 alternations. Dr. Hudson should note that this mean number which, by the way, was only used to compare the qualities of transverse and longitudinal sections, was derived from three under-annealed strips, two properly annealed ones, and one " burnt " one.

Replying to the written discussion, he had very little to add to what he had already written, with regard to Dr. Greenwood's and Dr. Hutton's interesting communication. All his own materials, without exception, had been better after treatment with manganese,

and in this view he was upheld by the experience of several successful Sheffield casters of the alloy.

He was very glad to receive confirmation of the greater ductility of nickel-silver strips cut transversely to the direction of rolling, a conclusion which he (the author) had arrived at from results of the alternating-stress test. Mr. Johnson's explanation appeared to fit in well with the facts

NOTE.

ALUMINIUM PRODUCTION BY ELECTROLYSIS ; A NOTE ON THE MECHANISM OF THE REACTION.*

By RICHARD SELIGMAN, Ph.Nat.D.

In the course of his paper on " Electric Furnaces as Applied to Non-Ferrous Metallurgy " in a recent issue of the *Journal*,† Professor Stansfield describes the production of aluminium by the electrolysis of a fused mixture of cryolite and alumina, and illustrates the course of the main reaction by means of the conventional formula

$$Al_2O_3 + 3C = 3CO + Al_2.$$
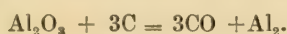
In a communication on this paper Dr. G. H. Bailey ‡ points out that this formula does not truly represent the changes which take place.

Dr. Bailey's communication clearly releases the writer from the silence he has imposed upon himself for nearly ten years, and he therefore proposes to give a very brief account of some work which resulted in proving the fallacy of the accepted view on this subject, and in releasing the aluminium industry, of this country at any rate, from one serious brake on its progress.

As Professor Stansfield correctly states, it has been assumed heretofore that carbon monoxide is the sole gaseous product of the electrolytic reduction of alumina. Thus, for instance, Richards,§ states that " On passing a direct current (through the electrolyte) . . . aluminium appears at the cathode and oxygen at the anode. If the anode is of carbon, carbonic oxide is there evolved."

A more apposite statement and one from which the harmful effect of this theory may be inferred is that of Haber,‖ who is concerned to prove that a certain weight of aluminium was not produced in the course of his experiments, and who supports his contention by stating that the anode carbon consumed was insufficient for the production of any more aluminium than that actually found. He says : " Direct proof can be adduced that 1040 grm. of aluminium were not generated.

. . . For every grm. of aluminium (actually found) almost 1 grm. of carbon was consumed. Now the formula $Al_2O_3 + 3C = 2Al + 3CO$ demands for the production of 1 grm. of aluminium the consumption of $\frac{2}{3}$ grm. of anode carbon. As some of the carbon was at the same time burnt directly the carbon consumption (in the experiment) was not much higher than was to be theoretically anticipated."

This, then, was the generally accepted view when the present writer approached the subject at the beginning of 1905, and so far as he is aware no public doubt has been cast upon its validity until the appearance of Dr. Bailey's statement cited above.

It is necessary to point out at this stage that a correct appreciation of the mechanism of the reaction whereby aluminium is produced in the electric furnaces is not only interesting from a purely scientific point of view, but is also of very great practical importance, because the anode consumption is one of the main items in the cost of production of aluminium, and it is clear that if the assumption be made that for every three units of aluminium produced two units of carbon must necessarily be consumed a downward limit is put to the possible reduction of this source of expenditure.

From observations made of the electric furnaces at work the writer soon reached the conclusion that the accepted "theoretical carbon consumption" was a myth, and that it should be practicable to work with a far lower consumption than had up till then been considered possible. At that time, however, he found his efforts to improve the carbon ratio hampered by the assertion that it was useless to spend money on experiments with the object of reducing a comsumption which already approached very nearly to the figure demanded by "theory." Nevertheless in a series of large scale experiments made avowedly with a different object, a carbon consumption of well below the "theoretical" figure was attained early in 1907. Experiments on a larger scale and in many directions were immediately started, and by the summer of 1907 the fact that carbon monoxide was not necessarily the sole gaseous product of the reaction had been finally demonstrated. As a result of the explosion of the fetish of a "theoretical" carbon consumption of 66 per cent. the present-day consumption has, as Dr. Bailey says, been reduced to a very much lower figure with financial benefits which are very considerable. The improvement attained has been accompanied by a number of subsidiary advantages upon which it is not necessary to dilate here.

It may now be of interest to give one or two examples of the composition of the anode gases produced in the electrolysis of aluminium which illustrate the correctness of the opinions expressed above, but before doing so it is necessary to point out that the conditions of an aluminium furnace make it somewhat difficult to collect the anode gases in a state of complete purity.

The method adopted was to encase one of the anodes in a sheet metal bell and to aspirate the gases from this bell into the usual

collecting vessels. Care had to be taken not to suck air into the bell (which could not be dipped right into the electrolyte owing to the corrosive nature of the latter), whereby secondary oxidation of the carbon monoxide might have been brought about. Although such infiltration was not entirely avoided, it will be seen from the proportion of nitrogen in the gases that the amount of air introduced was far less than would account for the carbon dioxide found.

Experiment I.

Temperature of electrolyte, 945° C.
Composition of anode gas—
    Carbon dioxide, 45·6 %
    Oxygen, 0·8 %
    Carbon monoxide, 43·6 %
    Nitrogen, 10 %

Anode consumption of furnace normal.

Experiment II.

Temperature of electrolyte, 1055° C.
Composition of anode gas—
    Carbon dioxide, 6 %
    Oxygen, 1·2 %
    Carbon monoxide, 86·4 %
    Nitrogen, 6·4 %

Anode consumption high.

These experiments were made at a later date in conjunction with Mr. A. V. Hussey. They are selected because of their bearing upon the question raised by Professor Stansfield as to whether the composition of the gases varies with the temperature of the system. It will be seen that the analyses tend to indicate the validity of Professor Stansfield's suggestion, and the experiments were in fact designed to answer this question. It must be remembered, however, that no precise numerical agreement with theory is to be expected, because the temperature of the electrode is by no means uniform throughout the portions immersed or in contact with the gases.

Some further experiments were carried out by the writer with the late Mr. H. B. Phillimore (by whose death in her service this country lost a brilliant experimenter and a brain of exceptional originality).

Owing to the difficulties experienced in eliminating atmospheric contamination in a commercial furnace, these experiments were made on a laboratory scale in the Electrical Department of University College, Gower Street, where Professor Fleming kindly gave facilities for the work to be done.

Experiments so far published upon the production of aluminium on a laboratory scale have, in their efforts to simulate practical conditions, always overlooked one of the most important, namely, current density.

It is well known that in the aluminium furnace the heating is done by the electrolyzing current, no external source of heat being required.

Experimenters have been anxious to reproduce this condition. but have overlooked the fact that the loss of heat from a laboratory furnace is far greater, proportionately, than that from a full-size commercial unit. In order to make up for this loss of heat current densities have been applied which are far in excess of those used in practice, and consequently the conditions obtaining in these laboratory furnaces have been totally different from those found in practice.

Mr. Phillimore and the writer considered that the question of the source of heat was entirely irrelevant, and that in order to construct a laboratory furnace which would truly represent the practical conditions, external heating would have to be applied so as to neutralize the excessive loss of heat to which these diminutive furnaces are subject. By constructing such a furnace. the external source of heat being either gas or electricity, it was found possible to produce aluminium under normal conditions in a bath having a capacity of about 150 grm. of electrolyte only. So far as the experiments went they indicated that all the phenomena of a large furnace could be reproduced " in parvo " by this simple device.

In order to prevent the infiltration of oxygen the electrolysis was carried out in a slow stream of nitrogen. Under these conditions gases containing more than 3 vols. of CO_2 to 1 vol. of CO were obtained before the experiments were interrupted, temporarily it was then thought, but in fact permanently.

Dr. Bailey in his communication rightly demolishes the old accepted formula, but replaces it by another, namely,

$$2Al_2O_3 + 3C = 2Al_2 + 3CO_2.$$

The view of the writer at the time was that the primary product of the electrolysis was oxygen. and that whether oxygen, carbon dioxide. or carbon monoxide resulted was dependent upon such factors as temperature, current density, physical properties of the carbon anode, rapidity with which the gases were removed from contact with the anode, and similar factors.

The experiments designed to prove the correctness or otherwise of this view had to be abandoned before any decision had been reached, but as Dr. Bailey has had many years and opportunities for carrying on the work begun by the writer it is to be hoped that he has reached some definite conclusion on this question which, now that he has broached the subject, he can make public.

COMMUNICATIONS.

Professor H. C. H. CARPENTER, Vice-President, wrote that, in his opinion, Dr. Seligman had contributed a most important note in connection with the production of aluminium by electrolysis, and that his action at the meeting in asking that his paper should not be discussed ought not to be construed other than as an act of unselfishness to enable other papers to be debated at greater length.

It was quite clear from the evidence brought forward that the time-honoured equation :

$$Al_2O_3 + 3C = 3CO + Al_2$$
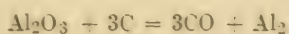
stated in this absolute form, did not represent the course of the reaction which was liable to be affected, as the author suggested, by a number of factors, such as "temperature, current density, physical properties of the carbon anode, and the rapidity with which the gases were removed from contact with the anode." In any case, it was hardly open to doubt that the primary product set free at the anode must be oxygen.

It appeared that the situation was one which in this country only Dr. Bailey could clear up, and it was to be hoped that he would do so. The fact, however, that the author had shown that under certain conditions the gases set free in a small-scale experiment contained more than 3 volumes of carbon dioxide to 1 volume of carbon monoxide indicated that—provided the conditions were suitably chosen—the reaction could be made to approximate much more nearly to the equation :

$$2Al_2O_3 + 3C = 2Al + 3CO_2.$$

The practical importance of this could hardly be over-estimated, for it meant an approximation to a halving of the anode consumption.

Dr. R. S. HUTTON, Member of Council, wrote that it was doubtless of interest and value that Dr. Seligman should bring forward this question of the mechanism of the reduction of alumina, but the statement of Professor Stansfield in his general paper on Electric Furnaces should not be taken as representing the views held even more than ten years ago by those who had worked on this electrolytic process. He (Dr. Hutton) had for many years taken an interest in the problem of the direct reduction of alumina by carbon,[*] and whilst disclaiming any practical acquaintance with the electrolytic process, had the good fortune to discuss the mechanism of the electrolysis with C. M. Hall

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[*] R. S. Hutton and J. E. Petavel, *Philosophical Transactions*, 1908, A, vol. ccvii. pp. 446–450.

in 1902, and also with the late P. L. T. Héroult shortly afterwards. The consideration of the process, as one in which the decomposition is directly or indirectly electrolytic, seemed to be quite generally held,* and one would naturally expect the oxygen, thus set free at the anode, to react at these temperatures to form chiefly carbon dioxide, as indeed had been previously noted.†

Dr. Seligman, replying to the written discussion, wrote that he feared that Dr. Hutton had largely misunderstood his (the writer's) contentions. It was nowhere suggested in the paper that either Hall or Héroult had regarded their process as other than electrolytic. In fact, in the very article referred to in the paper, Richards, who he believed was in close personal touch with both inventors, clearly stated that the process was purely an electrolytic one. This did not prevent Richards from assuming that the gaseous products were exclusively carbon monoxide, nor from basing calculations on this assumption. Haber's statements (cited in the paper) were sufficient evidence that this view was generally held at the time and of its influence on the industry, and it was significant that in various communications of the following year, in which Haber ‡ described the results of his investigations in America, he not only considered it unnecessary to correct his assumptions, but stated that his own observations were generally borne out by what he there saw and learned.

With regard to this country, to which he had especially referred in his note, he (Dr. Seligman) could state with some authority that at the time referred to no one connected with the manufacture of aluminium had the remotest doubt as to the validity of the older equation, and in point of fact the electrolysis as then conducted did not yield, as Dr. Hutton assumed, " chiefly carbon dioxide," but almost exclusively carbon monoxide. Nor was there any reason to assume that the industry in this country was at the time technically inferior to that of other countries.

To say, in face of those concrete facts, that " one would naturally expect . . . chiefly carbon dioxide," was strangely reminiscent of the action of certain grandees of Spain when shown how an egg might be made to stand upon its apex.

Having said so much, historical accuracy made it necessary to cite three references in literature to the generation of carbon dioxide during the production of aluminium by electrolysis—namely, Lorenz, *Electrolyse Geschmolzener Salze*, Part I., p. 96 ; Minet, " Production of Aluminium," p. 219 (1905), and Gin, cited by Dr. Hutton.

The first of these was an obvious misprint. The second was raised as an hypothesis, but was rejected by its author in favour of his own

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* P. L. T. Héroult, *Congrès Intern. des Mines et de la Métallurgie*, Paris, 1900. *Bulletin de la Société de l'Industrie Minerale*, (3) vol. xiv.
† Gustave Gin, *Verein des Intern Kongress für Angew Chemie*, Berlin, 1903, vol. iv. p. 501.
‡ *Zeitschrift für Elektrochemie*, 9, 1903, p. 360.

theory of the electrolysis which had long since been abandoned. The third was adduced in the course of a theoretical paper to square with certain experimental data which, if they proved anything, proved that carbon monoxide was produced and not carbon dioxide.

These isolated references could not, therefore, be held to invalidate in any way his (Dr. Seligman's) statement as to what the generally accepted view was at the time in question.

The point of main importance was, however, that referred to by Professor Carpenter, namely : Was even the new equation correct, or should the formation of the oxides of carbon be considered as independent of the electrolysis ?

METAL MELTING AS PRACTISED AT THE ROYAL MINT.*

By W. J. HOCKING.

A BRIEF general account of the Melting Branch of the Royal Mint and its work might form a suitable preface to this paper.

In this Branch bars of the various coinage alloys are cast, preparatory to rolling. The metals used are usually procured in the form of fine ingots, and are alloyed in the proportions shown in the following statement :

Standard gold : $91\frac{2}{3}$ per cent. gold ; $8\frac{1}{3}$ per cent. copper.
Imperial silver : $92\frac{1}{2}$ per cent. silver ; $7\frac{1}{2}$ per cent. copper.
Coinage bronze : 95 per cent. copper ; 4 per cent. tin ; 1 per cent. zinc.
Cupro-nickel : 75 per cent. copper ; 25 per cent. nickel.

In addition to the fine ingots and alloy the average charge, to the extent of about one-third of the total, consists of scrap metal from the various processes of manufacture, returned for melting.

The bars cast are about 2 ft. long, but differ in width and thickness according to the denomination of coin desired. The width varies from 4 in. in the case of bars for bronze coins to $1\frac{1}{4}$ in. in the case of those for threepences, and the thickness from $\frac{3}{4}$ in. for cupro-nickel bars to $\frac{3}{8}$ in. for bars for bronze. The bars are rolled in another department to the thickness of the coin required.

The average weight of the various classes of coinage metals cast annually during the last five years was about 2000 tons, or a mean rate of a little over 7 tons (7000 kilos) for the working day.

In melting gold and silver for coinage work, great care must be taken to secure in result the correct proportions of metals in the alloys as they are legally prescribed. The limits of variation from

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exact fineness are narrow, and are specified in the Coinage Act of 1891 (54 & 55 Vict., c. 72) as two parts per thousand for gold and four parts per thousand for silver. The variations permitted in practice are much less than these, and the necessity that the bars cast should be uniform in composition tends to restrict the size of the charges. The volume of the charge is mainly determined by the convenience of stirring it when molten and before pouring. Gold and silver bars are isolated in their respective " pots " until they are reported by the assayer to be either suitable or unsuitable for coinage. The usual charge of standard gold is 2800 oz., or 87 kilos, and of silver 6000 oz., or 187 kilos.

Two sets of furnaces are erected in separate rooms, the set of smaller furnaces being reserved exclusively for melting gold. The set of larger furnaces is used for melting silver, bronze, and cupro-nickel, crucibles of the same size being used for all three metals. About 400 lb., or 182 kilos, is the weight of the charge of each of the two baser metals.

REORGANIZATION OF MELTING PLANT.

Owing to a steady increase in the demands upon the Mint in recent years for coinage, it became necessary to extend the capacity of the Melting Branch as well as that of other operations of coinage. It was not possible to enlarge the rooms for melting without a complete reorganization of the whole Branch. Accordingly, the site was cleared, and new buildings were erected during 1910 and 1911. The furnaces were re-built and adapted for gas fuel in substitution for coke. First of all, however, a protracted series of experiments was made with various classes of fuels and burners, and the most satisfactory results as to speed of melting and economy of cost were obtained by the use of coal-gas at low pressure. These experiments numbered over 250, and were made with 19 different burners for oil and for gas, most of the burners being tried under various conditions of air and fuel pressures.

Unexpected circumstances arising during the transition period necessitated the adoption of experimental furnaces on a magnified scale. On the assumption that gold coinage would be suspended for a considerable period, the gold melting house was transferred to the builders early in March 1910. Before the end of the month,

owing to public demands, an immediate resumption of gold coinage became imperative. Acting upon results of experiments made with oil and gas in 1909, four (subsequently increased to five) gas-fired furnaces were erected in a disused smithy. This small workshop, only 860 sq. ft. in area, was provided with the usual fittings required in connection with the casting of gold bars for coinage, and was occupied for that purpose from May 1910 to March 1912.

A view of this improvised melting house is given (Fig. 1), showing the four furnaces and the general arrangement of the room.

FIG. 1.—View of Improvised Gold Melting House.

The coinage demands proved heavier than usual, and during this period $874\frac{1}{4}$ tons of standard gold of the value of £111,199,403 were melted, the average melt for a working day being 1·829 tons (1858 kilos), or £232,634 in value. In spite of drawbacks due to successive modifications of the new burners and to inexperience with gas as a fuel, the rate of out-turn was much accelerated as compared with former rates obtained with coke fuel. Although the total amount required for coinage was considerably in excess of the usual demands, a high rate of output per furnace was maintained throughout the period, and it was found possible with fewer furnaces to supply the rolling-mills with sufficient bars. For the ten preceding calendar years, the average annual production from eight coke-fired furnaces was 191 tons, while in 1910–12,

with four (five for part time) gas-fired furnaces the annual out-turn was 437 tons, the crucibles used being increased in size in the latter period. The bars produced showed a greater uniformity in composition, and a decrease in the rate of waste in melting. A special test occurred in October 1910 of the efficiency of the four experimental furnaces during a long run which extended continuously throughout $27\frac{3}{4}$ hours. The total amount of gold melted was 257,052 oz., or 7·87 tons (7996 kilos), which is upwards of a million sterling in value. There were 102 pourings, and the consumption of gas was 32,000 c. ft.

New Furnaces for Melting Silver and Bronze.

The larger of the two new rooms for melting operations was completed before the close of this probationary period in the smithy, and work was commenced therein in January 1911. Fig. 2 is a plan of this room and shows the general arrangement of the plant. The room measures 105 ft. by $52\frac{1}{2}$ ft. Sixteen furnaces are constructed in line towards the centre of the room, arranged in two batteries, one of ten, measuring 34 ft. by 4 ft. 6 in., and one of six, measuring 21 ft. by 4 ft. 6 in.

The furnaces are built of Stourbridge firebrick, each well being 19 in. in diameter and 32 in. deep. The wells are lined with circular bricks, 3 in. thick, jointed with a refractory material composed of carborundum, firesand, and silicate of soda, which is also used as a backing for the bricks. The face of the bricks forming the interior of the wells is treated with a wash made up of the same materials.

The whole mass of brickwork is braced together by a framework of iron bars to resist expansion, but is not enclosed with iron casing.

For convenience of charging the furnaces and of access to the crucibles for stirring the contents, the furnaces stand 27 in. above the floor level. The tops are covered with cast iron plates, 1 in. thick, bedded upon a $\frac{1}{2}$-in. layer of asbestos cement. The plates are fitted loosely in sections to admit of expansion, and are shaped to allow a lip of brickwork around each furnace hole, $4\frac{1}{2}$ in. broad. This ring of brickwork is made to rise slightly above the level of the iron tops, and serves to prevent the fusion of the iron coverings.
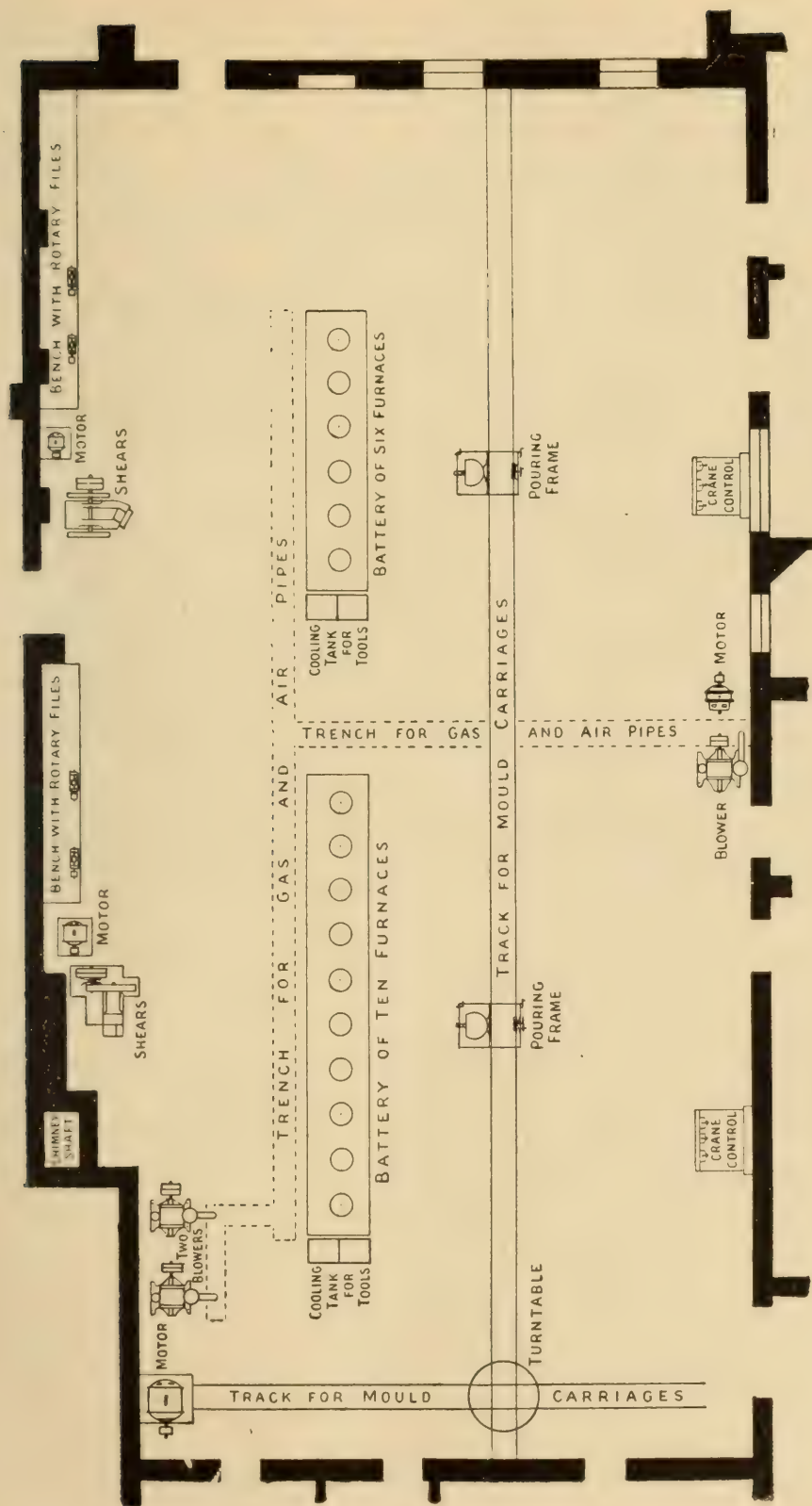
Fig. 2.—Plan of Silver and Bronze Melting House.

The tops were at first carried to the edge of the furnace holes, and the molten iron scored the face of the furnace linings, necessitating frequent renewals.

A circular firebrick, 27 in. in diameter and 3 in. thick, is used to close the mouth of the furnace hole during melting. This cover is surrounded by two semicircular iron bands, $\frac{3}{4}$ in. thick, bolted together to form a frame. The cover, which weighs $1\frac{1}{2}$

COVER LIFTED FOR REMOVAL
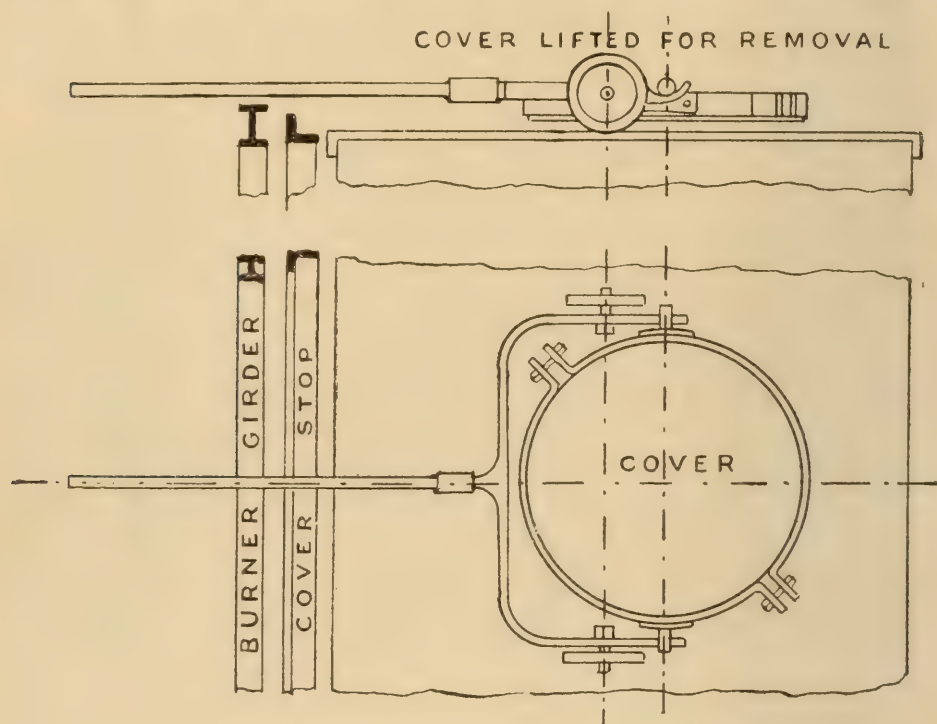
Fɪɢ. 3.—Cover Remover.

cwt., is lifted and wheeled into any desired position on the furnace top by means of a portable cover remover, designed in the Mint, and shown in plan and elevation in Fig. 3. The two ends of the lifter engage with a couple of lugs at opposite sides of the frame of the cover. A long detachable handle fitted with a socket serves to raise and guide the cover in the required direction, an operation easily performed from the back of the furnace. One of these tools is provided for each pair of furnaces.

An electric-driven overhead travelling crane of 5 cwt. capacity hoists the crucible of molten metal from the furnace, and transports it to one of two pouring frames (Fig. 1). The movements of the crane are directed by means of switches situated at two plat-

forms shown in the plan (Fig. 2). When in position for pouring, the crucible is gradually tilted by worm gearing connected with the frame through the quadrant of a circle, and the contents poured into iron moulds. The moulds are set up in batches of about forty in wheeled carriages which travel on a permanent track laid lengthwise of the room, with a turntable and side-track
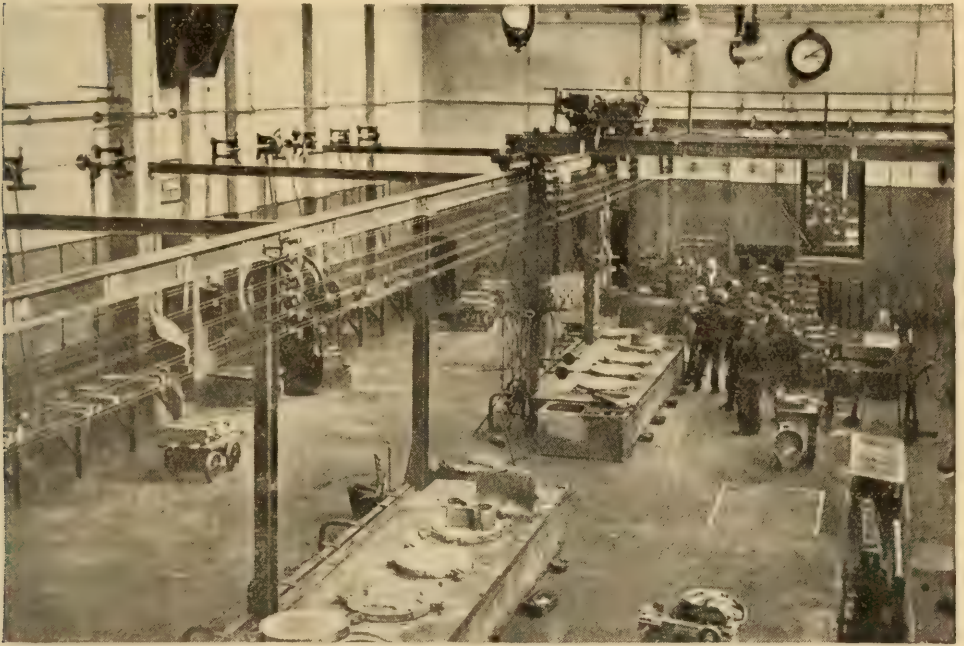
FIG. 4.—View of Silver and Bronze Melting House.

at one end (Fig. 2). During the process of pouring, the forward motion of the carriage on the rails as the moulds become full as well as the upward movement of the crucible is secured by rack and pinion gearing attached to the frame, the motions being actuated by separate wheels, controlled by two workmen. Fig. 4 is a photograph giving a general view of the centre of the room, showing the position of the furnaces, travelling crane and pouring frame.

FUEL SUPPLY AND COMBUSTION.

Experience gained with the use of gas fuel in the temporary gold melting house, to which reference has already been made, pointed to the desirability of securing a liberal supply of gas at a constant pressure. The supply of gas under these conditions was undertaken by the Commercial Gas Company, and a 12-in.

street main was laid to the meter-house, where four meters, each
of 1000 light capacity, were installed, one to act as a reserve.
From the meter-house a 9-in. service main supplies the Melting
Houses direct, and the consumption of gas in melting operations
is readily ascertained.

In the large house (Fig. 2) the gas is delivered at the furnaces
through a 6-in. service pipe at a steady pressure of 3 in. of water
at the furnace.   As the total consumption of the 16 large furnaces
is about 15,000 c. ft. per hour, the provision for delivery is well
in excess of the requirements.   An ample reserve is considered
essential to uniformity in results.

Three rotary blowers of the Reichhelm type obtained from
the American Gas Furnace Co. are used to supply air for the
burning mixture (Fig. 2).   Each blower is capable of deliver-
ing 36,000 c. ft. of free air per hour at $2\frac{1}{2}$ lb. pressure.   All the
pressure blowers are motor-driven, and two are coupled to feed
the larger battery of ten furnaces.   The maximum horse-power
required to supply air under pressure for the whole of the furnaces
in the large room is 45.

The air and gas are supplied by pipes laid below the ground
level in a trench running parallel with the back of the furnaces.
The sizes of these pipes are sufficiently large to admit of one or
more furnaces being thrown in or out of action without disturbing
the steadiness of the supplies to the remainder ; that for air
is 9 in. and that for gas is 5 in. to the larger battery, and 4 in.
in diameter to the smaller.   Connecting pipes from each of the
two services are attached to a horizontal girder for support,
and conduct the air and gas into a mixer devised by Brayshaw.
A sectional drawing is shown by Brame,* but the pressures for
gas and air respectively stated thereon do not correctly describe
the Mint working conditions, which are 3 in. for gas and $2\frac{1}{2}$ lb.
for air.   Check gauges are in use to determine whether these
pressures are obtained at the furnaces.

Fig. 5, A, is a sectional elevation of the furnace, showing the
crucible, muffle and cover, the gas and air pipes with nozzle and
burner brick in position, and the main flue with its connections.

Fig. 5, B, is a back elevation, showing the gas and air pipes
with quadrant taps, and the girder support.

* " Fuel: Solid, Liquid, and Gaseous."   Arnold, 1914.   Fig. 31, p. 200.

Fig. 5, C, is a plan of two furnaces without their covers, each
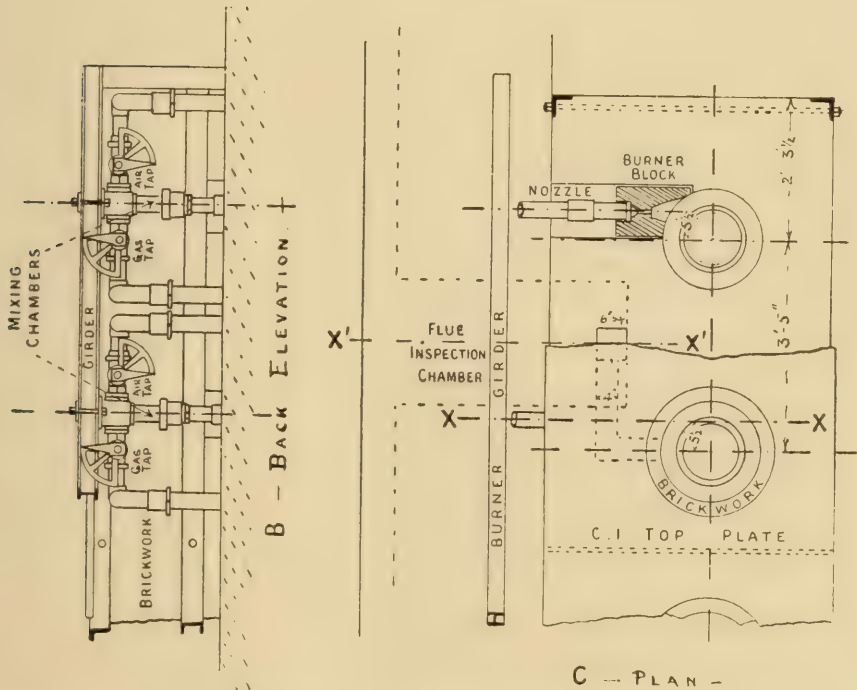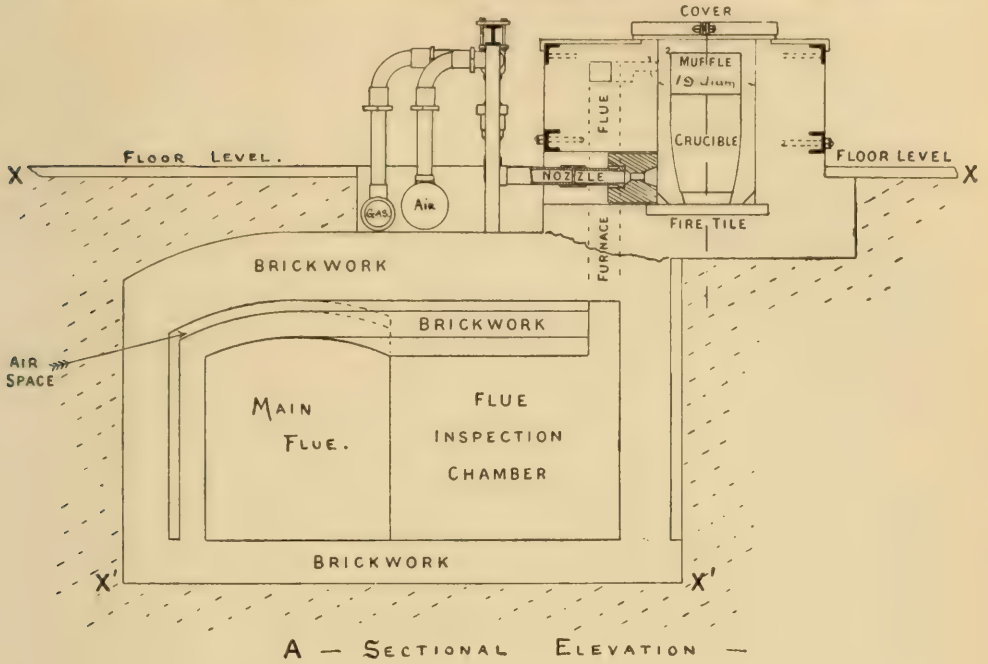
FIG. 5.—Gas Melting Furnace.

containing a crucible. One shows the top view with flue, and
the other the bottom with nozzle and burner brick.

The admission pipes to the mixing chamber are governed by valves, the levers of which move over a graduated quadrant. With well-constructed taps of this description the supply of gas and air can be regulated with precision. In the course of a heat these supplies require adjustment as the temperature rises in the furnace.

From the mixing chamber the gaseous fuel passes through a right-angled elbow pipe, $2\frac{1}{2}$ in. diameter, to the furnace. To adjust the length of flame to the capacity of the furnace and secure greater melting efficiency, the internal diameter of this
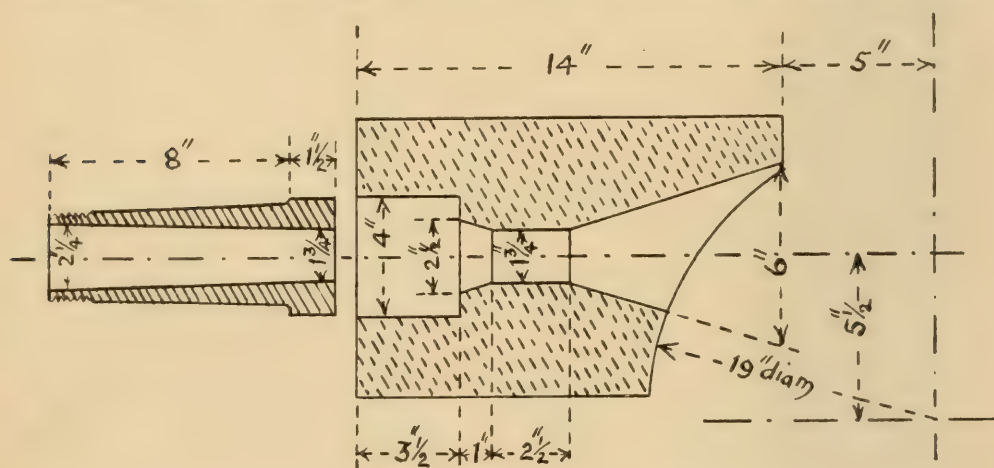
Gas-burner Nozzle.   Firebrick Burner Block.

FIG. 6.

pipe was reduced at its extremity to $1\frac{3}{4}$ in. The method of inserting the nozzle of the burner into the wall of the furnace, illustrated in Fig. 6, is the one yielding most satisfactory results. This method, which is regarded as essential with this class of furnace to an economical use of gas-fuel, was gradually evolved in the Mint, and was finally adopted in May 1912, as the result of a series of successive modifications.

An 8-in. end-piece, screwed in position and having a diminishing bore, forms the nozzle (Fig. 6), which is increased to 4 in. in outer diameter at its extremity and consequently presents a thickened ring of iron to the firebrick. It is easily detached and renewed in the event of corrosion or partial fusion. It may be mentioned here that the effective combustion of the gaseous fuel appears to be aided and the amount of noise reduced by the use of pipes and connections with a perfectly smooth interior.

To maintain this condition the mixing chamber and the delivery pipe to the furnace are periodically removed and cleansed from any accumulations of deposit.

The ignition hole of the furnace consists of a perforated firebrick of special shape, as shown in the sectional drawing given in Fig. 6. A circular recess, 4 in. in diameter, at the back of the block, which is $9\frac{1}{8}$ in. square, receives the iron nozzle which fits the recess closely, and is surrounded by asbestos packing well rammed in. The comparatively large block of firebrick serves to keep the nozzle relatively cool. At the bottle-neck the inlet is $1\frac{3}{4}$ in. in diameter, corresponding with the bore of the burner. The passage then opens out at an angle of 30° into the well of the furnace, where ignition takes place.

The burner block is built into the brickwork, and is set to one side of the horizontal axis of the furnace well in a position to induce the flame to pass between the crucible and the side of the furnace without impinging upon either.

The crucible, which is of the Morgan Salamander type and of a special mixture adapted for use with gas fuel, is placed centrally in the furnace upon a graphite stand, 10 in. in diameter and $2\frac{1}{4}$ in. thick.

A plumbago muffle or collar, 8 in. deep, rests on the crucible to increase its initial capacity, but no cover is used for the charge during melting in the case of silver and the baser metals. About 3 in. clear space is allowed round the crucible at its greatest diameter to admit of the lowering of the tongs which lift it from the furnace for pouring. When the furnace is closed, the top of the muffle is within 2 in. of the cover.

The gas flame on leaving the ignition hole travels round the crucible in an upward double spiral. The best results in economy and efficiency are obtained when combustion is complete in the furnace itself, no flame being emitted under the furnace cover nor carried into the flue aperture. To compensate for the lengthening of the flame which takes place as the temperature in the furnace rises during the progress of the melt, the supply of gas and air is regulated by means of the quadrant taps already mentioned. Similar adjustment to maintain the correct mixture becomes necessary in the event of any variation of the gas or the air from normal pressure.

The flue aperture is 4 in. by 2 in. in sectional area, with its axis 5 in. below the iron covering plates, and opens into a horizontal duct leading from the furnace to a vertical shaft, 6 in. square, which serves for two furnaces. This shaft is connected with the main flue, constructed below the floor level. The main flue (Fig. 5, A), which runs parallel with the line of furnaces, is 3 ft. by 3 ft. in section, and, before entering the chimney shaft, which is 60 ft. high, it passes through a condensing chamber provided with baffles to intercept any solid matter carried off by the flue gases.

Furnace Management.

For the prevention of accidents in the use of the large volumes of gas and air delivered to the furnaces, a recognized system of workshop procedure was necessary. The following routine was found from the first to work satisfactorily. All the air valves are opened, and the blower is then started to deliver air to the furnaces. Then, dealing with each furnace successively, the air valve is closed, the gas valve opened, the gas ignited, and the air valve re-opened to its utmost capacity. So soon as the whole series of furnaces is alight, the gas and air taps are adjusted to produce the proper burning mixture in each case.

In shutting off a single furnace, the gas valve is first closed, and then the air. When dealing with the whole battery, the gas valves are closed on all the furnaces, the pressure blower stopped, and the quadrant taps turned off.

Should the blower stop unexpectedly through the breakage of a belt or from other causes, all gas and air taps are closed immediately to prevent the suction of gas into the air pipe when the pressure is removed and the formation of an explosive mixture. In view of this emergency the air pipes are, in some cases, provided with non-returnable valves which are automatically brought into action as soon as the pressure ceases. Experiments are in progress to ascertain the simplest and most effective form of safety device for such a contingency.

The furnace linings receive close attention, which is repaid by a lengthened life. The surfaces are kept free from excrescences which would obstruct the free passage of the gas flame.

Accumulations of slag at the bottom of the furnace are cleaned out at frequent intervals. Faults in the brickwork arising from the alternate heating and cooling, or from other causes, are patched immediately. In general result the entire lining of a furnace is renewed two or three times a year.

Ventilation.

Provision is made for the ventilation of the melting house by means of fans. Three Blackman fans, situated one at each end and one at the side, are installed near the roof. These can be used either for supply or exhaust, as required. If two of the fans are drawing from the room, and one is discharging into it, the whole volume of air is changed every five minutes, independently of the doors, windows, and skylight. It is possible, therefore, to keep the room clear of the fumes which arise, especially during pouring, and also to maintain the general temperature of the workshop at a reasonably low level. The latter becomes a particularly important consideration during the melting of bronze and cupro-nickel in the hot weather, and bears directly upon the efficiency of the workmen. But the flue accommodation itself is amply sufficient for the removal of any products of imperfect combustion, should these occur in the furnaces, and no inconvenience in this respect has at any time arisen in the melting houses.

Comparison of Costs of Melting.

Records are kept in the Department of the results of melting with gaseous fuel for comparison with similar results obtained with coke. These results are available for a period of five complete years ended March 31, 1916, in the case of gas, and for five calendar years ended December 31, 1909, in the case of coke. The periods named cover extensive operations. During the five years, 1911–16, nearly 10,000 tons (over 10 million kilos) of metal were melted and cast into bars for coinage with a total consumption of 121 million cubic feet of gas.

A comparison of the records for the two periods shows an

economy in favour of gaseous fuel under each of the following
heads :

(1) Rate of output.
(2) Cost of fuel.
(3) Cost of graphite goods.
(4) Cost of labour.

(1) *Rate of Output.*—Except in the case of gold, crucibles of
the same capacity as formerly were used, but the time required
for the heats was shortened considerably. The rate of output
per furnace in the working day was correspondingly increased,
and this increase was especially noticeable in the case of the metals
requiring the higher temperatures. In 1909 and in 1913 the largest
amounts of cupro-nickel were melted, and, as these metals form
the most stringent tests to which the Mint furnaces are subjected,
the results of these years are selected to show the comparative
rates of out-turn.

Metal.	Average Melt per Furnace per Working Day of Ten Hours.		Increased Output per Furnace.	
	1909 (Coke Fuel).	1913 (Gas Fuel).		
	Cwt.	Cwt.	Cwt.	Per Cent.
Gold	5·2	9·8	4·6	88·5
Silver (bars for shillings) . .	5·7	12·8	7·1	124·5
Bronze	5·2	13·4	8·2	157·7
Cupro-nickel	3·6	9·4	5·8	161·1

The same furnaces are used successively for melting silver,
bronze, and cupro-nickel. As these alloys have melting points
varying more than 200° C. between the maximum and minimum,
the greatest economy is not effected in all cases. The rates
shown would no doubt be further improved if it were possible to
allot a suite of furnaces to each metal, and to modify the burners
according to the temperature required to melt each class of metal.

(2) *Cost of Fuel.*—The respective costs of coke and gas are well
known to vary considerably in different localities. They are also
liable to vary in the same locality throughout a given period,
although there is a fairly constant relation between the cost of one

as compared with the cost of the other. During 1905–9 the price of best foundry coke delivered broken for use at the Mint fluctuated from 35s. as a minimum to 42s. 4d. per ton as a maximum ; while during 1911–16 the discount price of gas per 1000 c. ft. varied only very slightly from 21d., except during nine months of 1915–16 when it was 18·2d. Although the price of gas advanced 12½ per cent. during the last five years, the net cost to the Mint remained practically stationary owing to the sliding scale of discounts allowed by the Commercial Gas Company.

On the total expenditure for fuel for the two periods of five years a cash saving of 3½ per cent. on the amount consumed per ton melted is shown for 1911–16. The amounts melted and the fuel consumed for the two periods are shown side by side :

	1905–9.	1911–16.
Gross amount of metal melted	4833 tons	9899 tons
Total consumption of fuel	2677 ,,	121 million cub. ft.
Consumption of fuel per ton melted . . .	11 cwt.	12,220 cub. ft.
Cost of fuel per ton of metal melted . . .	21·3s.	20·58s.

The above comparison is made on the basis of the gross amount melted. Owing to the general practice of melting two or more metals simultaneously, it was not possible to secure an extended series of records of the fuel consumption for one metal alone. None whatever are available for the coke period. The following rates of consumption for the various metals are approximately true for gas, but, being based upon readings for comparatively short runs, are subject to revision. The approximate specific gravities and temperatures of pouring are added in the table, as these are essential factors in the relative consumption of fuel.

Metal.	Approx. Specific Gravity.	Approx. Temperature of Pouring. ° C.	Cub. Ft. of Gas used per Ton Melted.	Cost in Shillings per Ton with Gas at 21d. per 1000 Cub. Ft.
Gold	17·3	1150	7,000	12·25
Silver . . .	10·35	1090	12,000	21·0
Bronze . . .	8·9	1165	14,500	25·375
Cupro-nickel . . .	8·8	1300	22,000	38·5

(3) *Cost of Graphite Goods*.—The crucibles used for both the coke-fired and the gas-fired furnaces were of the Morgan Salamander brand, the mixture being modified in the latter case to

suit the firing. A considerable extension of life was found when they were used with the gaseous fuel. In addition to minor causes, this was mainly due (*a*) to the greater uniformity of combustion in the furnace, and (*b*) to the absence of abrasion to the soft skin of the heated crucible, which is unavoidable during the periodical poking down of the fuel in the coke furnace.

The total inclusive costs for the two periods are placed side by side, and show that the rate per ton melted has been reduced by about one-third.

	1905–9 (*Coke Fuel*).	1911–16 (*Gas Fuel*).
Weight of metal melted	4833 tons	9899 tons
Total cost of crucibles, &c.	£9,625	£13,295
Cost of crucibles per ton melted	39·8*s*.	26·8*s*.
Rate of reduction in costs	...	32·6 per cent.

The figures for costs shown cover in each case the purchase of muffles, covers, stands, and stirrers as well as of crucibles. In the latter period the total amount includes advances in price due to the war, and also extra costs incurred in the earlier stages before the manufacturers supplied crucibles specially suited for use with gaseous fuel. The mixture now employed gives excellent results. The improvement in the quality of the crucibles is reflected in the reduction in the rate of cost per ton melted. Comparing the years 1911–12 and 1915–16, the first and last years of the gas period, the drop was from 37*s*. to 22·7*s*. per ton melted, and comparing the five years, 1905–9 (using coke), with last year, 1915–16 (using gas), the reduction was from 39·8*s*. to 22·7*s*., or about 40 per cent.

The two tables which follow are compiled to show the total costs for fuel and for graphite goods, as well as the average rates of these per ton melted, for the several years of the two periods under review.

(4) *Cost of Labour.*—Coke fuel necessitates considerable handling ; gaseous fuel is delivered at the furnace without manual labour. During 1905–9, the average annual consumption of coke was 535 tons. Two men were employed in each melting house to transfer the coke from the store to the furnaces as required and to remove the ashes and clinker. This labour, as well as that of periodically feeding the furnaces, was abolished with the introduction of gas fuel. The coke store, which was 37 ft. by 12 ft., was no longer required for this purpose, and this valuable floor

COSTS FOR FIVE YEARS (1905–9) WITH COKE FUEL.

(*Fuel and Crucibles.*)

Period.	Weight of Metal Melted.			Expenditure.			Cost per Ton (Average).			Percentage of Total in Bronze and Cupro-nickel.
	Gold and Silver.	Bronze and Cupro-nickel.	Total.	Fuel (Coke).	Crucibles, Muffles, &c.	Total.	Fuel.	Crucibles.	Total.	
	Tons.	Tons.	Tons.	£	£	£	£ s. d.	£ s. d.	£ s. d.	Per Cent.
1905	386	131	517	561	1,019	1,580	1 1 8	1 19 5	3 1 1	25
1906	630	297	927	837	1,810	2,647	0 18 1	1 19 1	2 17 2	32
1907	921	293	1,214	1,227	2,208	3,435	1 0 3	1 16 4	2 16 7	24
1908	476	501	977	1,081	2,044	3,125	1 2 2	2 1 10	3 4 0	51
1909	523	675	1,198	1,455	2,544	3,999	1 4 4	2 2 5	3 3 9	56
	2,936	1,897	4,833	5,161	9,625	14,786	1 1 4 (Average)	1 19 10 (Average)	3 1 2 (Average)	39

COSTS FOR FIVE YEARS (1911–16) WITH GASEOUS FUEL.

(*Fuel and Crucibles.*)

Period (April to March).	Weight of Metal Melted.			Expenditure.			Cost per Ton (Average).			Percentage of Total in Bronze and Cupro-nickel.
	Gold and Silver.	Bronze and Cupro-nickel.	Total.	Gas-Fuel.	Crucibles, Muffles, &c.	Total.	Fuel.	Crucibles.	Total.	Per Cent.
	Tons.	Tons.	Tons.	£	£	£	£ s. d.	£ s. d.	£ s. d.	
1911–12	1,048	445	1,493	1,639	2,767	4,406	1 2 0	1 17 0	2 19 0	30
1912–13	1,030	532	1,562	1,375	2,016	3,391	0 17 8	1 5 10	2 3 6	34
1913–14	828	1,301	2,129	2,307	2,850	5,157	1 1 8	1 6 10	2 8 6	61
1914–15	1,675	673	2,348	2,291	2,971	5,262	0 19 6	1 5 4	2 4 10	29
1915–16	1,790	577	2,367	2,593	2,691	5,284	1 2 0	1 2 8	2 4 8	24
	6,371	3,528	9,899	10,205	13,295	23,500	1 0 7 (Average)	1 6 10 (Average)	2 7 5 (Average)	36

space was embodied in the main furnace room. Ashes and clinker were ground and washed for the recovery of the precious metals. With gas fuel the grinding and washing is confined to crucibles and furnace linings, and the bulk for treatment is considerably reduced in consequence. The weight of the grindings for each 100 tons of gold and silver melted under the two systems is estimated to be as follows :

		Gold.	Silver.
With coke fuel	. . . .	4·3 tons	3 tons
With gaseous fuel	. . . .	1·3 ,,	0·5 ,,

Viewing the staff as a whole, the number of men required for a given out-turn of coinage bars was reduced by the change of practice at the rate of about 20 per cent.

		1905–9.	1911–16.
Average annual melt	. . . . . .	967 tons	1980 tons
Average number of men employed	. . .	16·2 men	27 men
Average number of men per 100 tons melted	. .	1·68 ,,	1·36 ,,
Rate of reduction of labour	. . . . .	...	19 per cent.

A comparison of the actual expenditure for the two calendar years 1909 and 1913 was made under three headings, viz. Fuel, Crucibles, and Wages, the money value of which can be most readily ascertained. The result showed a saving in the latter year of 22·8s. per ton, or 27·6 per cent. of the total cost in 1909. This economy on the year's melt of 1958 tons, at the average rate of 22·8s. per ton, amounted to £2232. For this comparison, piecework wages which vary with the rate of output is excluded, and only standing wages which vary with the amount of labour required is stated.

Year.	Weight of Metal Melted.	Annual Expenditure.				Rate of Cost per Ton Melted.			
		Fuel.	Crucibles, &c.	Wages.	Total.	Fuel.	Crucibles, &c.	Wages.	Total.
	Tons.	£	£	£	£	*s.*	*s.*	*s.*	*s.*
1909	1,198	1,455	2,544	939	4,938	24·3	42·4	15·7	82·4
1913	1,958	2,162	2,613	1,061	5,836	22·1	26·7	10·8	59·6

The chief item of cost occurring with gaseous fuel but not with coke arises in the provision of power for the pressure blowers.

This item, however, is a comparatively small one.   In the large room the electric current supplied is at the rate of 2 B.T. units per furnace-hour.   The all-round cost for power is estimated to be at a rate not exceeding 2s. per ton melted, taking the current at 2d. per unit.   This item has not been included in the foregoing tables of costs, as it is considered that sundry minor economies effected under the new system balance this additional outlay.

In connection with the general subject of costs, it may be of interest to state the initial outlay made in providing the new buildings with the plant specially required for melting with gas. The cost of the motors and blowers, the four 1000-light meters, the pipes and connections for the gas and air services and the burners with their accessories was £1984.   The capacity of this melting plant under ordinary conditions is represented by an output of about 2000 tons annually.

With reference to the foregoing statistics, it might remove possible misapprehension to state that the figures are compiled from the working accounts of the Department, and no allowance has been made for such delays and accidents as have occurred in the routine of work during the periods under review.   This feature should be borne in mind in comparing the results shown for the last five years with those of special test runs frequently quoted by furnace manufacturers.   In point of fact the weight of the metal which passed through the crucibles is understated in the above returns.   No record is made of the weight of the spillings, filings, rough ends, and faulty bars which occur more or less with each pouring, and are re-melted in the course of the day's work.   The proportion re-melted but not noted in the books varies with the several metals and also with the quality of the ingots, but the average weight melted twice on the same day is estimated to be between 2 and 3 per cent. of the total amount given to melt.   Therefore, to ascertain more approximately the gross amount melted with the gas recorded at the meters, the weight stated above for 1911–16 should be increased at the rate of (say) 2½ per cent., that is, from 9899 tons to 10,146 tons.

Recovery of Metal.

An important factor in Mint work is the adequate control of the precious metals given to melt. In an ordinary working day the amount of gold melted is more than 3 tons and is worth nearly £400,000, and of silver about 9 tons, which in coinage value is £80,000. Obviously a satisfactory account of these values must be rendered at the close of the day. And the recovery of the metal given to work was a feature considered in choosing the form of furnace. It was ascertained by experiment that spillings of metal and splashes from the crucible were recoverable with comparative ease from a furnace with a closed bottom, while this form was more uniform in heating results than one with a removable bottom.

Larger deposits of metal in the furnace owing to fractured crucibles were also found to be recoverable. Occasionally a crack develops in the crucible when the metal is molten, and a certain amount runs into the furnace. This metal is allowed to cool after the crucible is drawn, when it forms a solid mass round the graphite stand. It is then possible to chip out the soft plumbago and withdraw the *culot* of metal from the furnace.

The bottom of the furnace consists of a solid fire tile, 20 in. square and 2 in. thick, and at the junction of the lower course of brickwork and the tile a moulding of fireclay is introduced, rounding off the sharp corner. Consequently, the spillings and runners on cooling have their under side domed in shape and relieve readily. If the furnace is badly worn and the metal becomes keyed into the side, the lower course of brickwork is removed.

Gold Melting House.

The furnaces for melting gold are similar in construction but of smaller dimensions than those for melting silver and bronze. The room contains ten furnaces built in a single battery, and the internal measurements of the well-holes are 12 in. in diameter and 21 in. deep. The melting capacity of each furnace is about 17,000 oz., or 529 kilos per working day of ten hours. As the general arrangements of the plant are similar to those in the larger room it is hardly necessary to specify the details.

COAL-GAS AS A FUEL FOR MELTING NON-FERROUS ALLOYS.*

By GEORGE BERNARD BROOK
(Lecturer in Non-ferrous Metallurgy in the University of Sheffield).

THE use of gas for the melting of metals has always seemed to the author to be ideal. Some years ago he, in conjunction with Mr. C. O. Condrup, determined the relative costs and efficiencies of coal, oil, and gas, as fuels for the melting of brass, over a continuous run of fourteen hours. The experiments were carried out in furnaces side by side, in 30-lb. heats, the furnaces being run, without intermission, for a period of fourteen hours. Each furnace was worked by an expert on that particular type, and each furnace was selected as being the most reliable and efficient one of its type at the time the test was taken. A section of the coke-fired furnace is shown below (Fig. 1). The summarized results of the test are shown in Table I., and the deductions drawn at the time from this test were as follows :

(*a*) That although the oil and gas furnaces were obviously working at a disadvantage in using a crucible smaller than the size for which they were built, they secured a larger output than the coke-fired type.

(*b*) The greatest speed with which the first cast could be made, starting with the furnace cold, was found to be with the oil-fired furnace.

(*c*) The minimum time taken for the melting of any of the charges was shown by the gas furnace, viz. nineteen minutes (time from charging to pouring).

(*d*) The total cost per 100 lb. of brass was distinctly in favour of the use of gas ; the relations being—gas, 100 ; coke, 135 ; oil, 267.

(*e*) The zinc loss, as might be expected, is lowest in the coke-fired furnace, as such loss is to some extent affected by the forced blast in the two other types of furnaces.

Section

Elevation

Plan

Scale of Feet
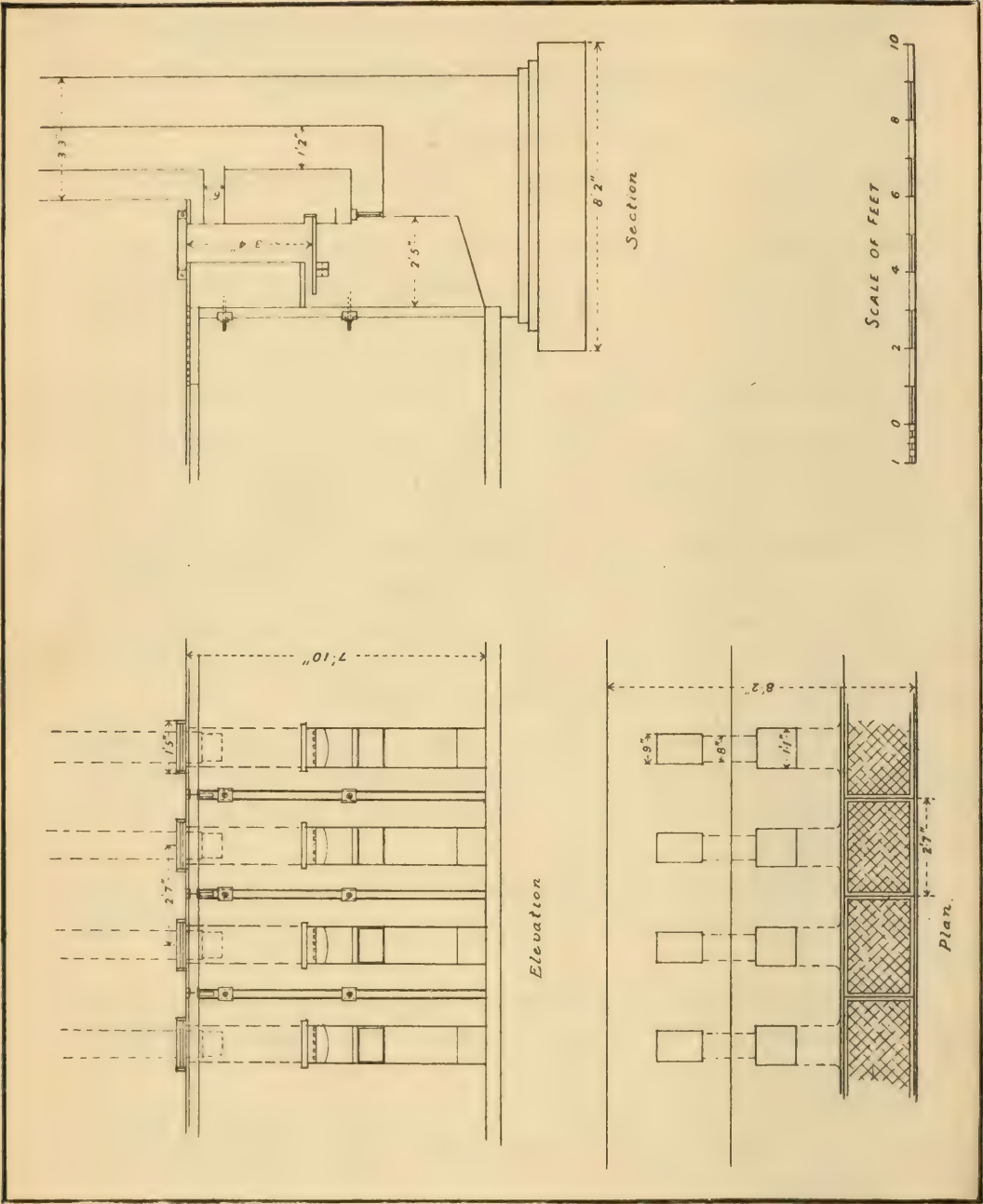
(*f*) The sulphur content is lowest in the oil-melted alloy, and highest in the brass produced in the coke-fired furnace.

TABLE I.—*Summary of Experimental Run of Fourteen Hours.*
March 10, 1914.

		Coke.	Oil.	Gas.
1	Output on 14-hour run (total, 2220 lb. brass) .	720 lb.	750 lb. (*a*)	750 lb. (*a*)
2	Weight of charge . .	30 ,,	30 ,,	30 ,,
3	Number of casts . .	24	25 (*a*)	25 (*a*)
4	Time taken for melting initial 30-lb. charge, starting cold furnace .	89 min.	70 min. (*b*)	78 min.
5	Time taken for melting subsequent charges, minimum . . .	22 ,,	20 ,,	19 ,, (*c*)
	Time taken for melting subsequent charges, maximum	37 ,,	41 ,,	34 ,,
	Time taken for melting subsequent charges, average	29 ,,	29 ,,	27 ,,
6	Fuel, cost of . . .	24*s.* per ton	80*s.* per ton	10*d.* per 1000 cubic ft.
7	Fuel, heat value (British thermal units) . .	12,960 per lb.	19,700 per lb.*	570 per cubic ft.
8	Consumption of fuel per 100 lb. brass melted .	66 lb.	4·1 gall.	383 cubic ft.
9	Cost of fuel per 100 lb. brass	8·6*d.*	15·3*d.*	3·8*d.* (*d*)
10	Electrical energy for blast at 1*d.* per unit . .	nil	3·3*d.*	1·1*d.*
11	Cost of graphite crucibles (on a basis of a 48 heat life)	2·5*d.*	3·3*d.*	3·3*d.*
12	Total cost of melting 100 lb. brass	11·1*d.*	21·9*d.*	8·2*d.* (*d*)
13	Zinc loss on 100 lb. brass .	0·40 p. ct. (*e*)	0·85 per cent.	0·44 per cent.
14	Sulphur (absorbed from fuel) per cent. per cast .	0·0040	0·0010 (*f*)	0·0026

It will be noticed that the cost of the gas in the above test was based on the current price as supplied to users of *gas-engines* in Sheffield (see summary above).

Whilst the author recognizes the limitations of the above tests, he thought it might be useful to have them for comparison, since they prompted the more extensive test, which forms the basis of this paper.

In order to make the test as drastic as possible, cupro-nickel (80 : 20) was chosen as the test alloy in view of the high temperature required for this particular material.

* The oil used was best Anglo-American.

In this further test every endeavour was made to ensure that the work should be on as large a scale as possible, closely following commercial practice, so that results obtained would be accepted by manufacturers as a guide to what might be expected in their own melting shops.

During the ten working days covering the period of the test, the total weight of metal that went through the furnace was 51 cwts. The material was subsequently rolled and passed on to the cartridge manufacturer, and made up into 0·303 bullet sheaths. Every detail that might interfere with the success of the experiments, or the reliance to be placed on the results of the test, was eliminated as far as one was able to foresee.

DESCRIPTION OF GAS FURNACE USED.

The furnace consisted of a self-contained unit, pit-fired pattern, taking a 60-lb. crucible. The body was of cast iron, and the heating chamber insulated. The lining of the furnace consisted of specially prepared refractory bricks.

The furnace was fitted with a double-hinged bottom door actuated by a lever to facilitate removal of metal in case of accidental spilling or breakage of crucible. The cover was mounted, as shown, on four wheels, so as to enable the crucible to be easily withdrawn for pouring. The burners were duplex, controlled by dial taps. The air under pressure was supplied from a belt-driven positive blower at a pressure of 3 to 6 in. of mercury. Special claim was made for the type of burner in that efficient mixing of gas and air was secured.

The Object of the Test.—The main points which the writer had in view were as follows :

1. Would ordinary (coal) gas give a temperature that was sufficiently high for the successful casting of cupro-nickel ?

2. What was the relation between the coke-fired furnace and gas-fired furnace from the following standpoints ?

    (*a*) Cost of melting.
    (*b*) Speed of melting.
    (*c*) Life of crucibles.
    (*d*) Wear and tear of lining and burner.
    (*e*) Melting losses.

CR

CRUCIBLE FURNACE

SCALE OF FEET
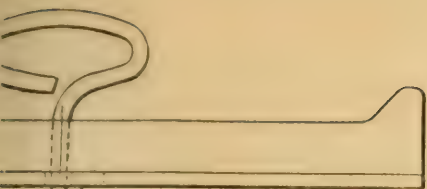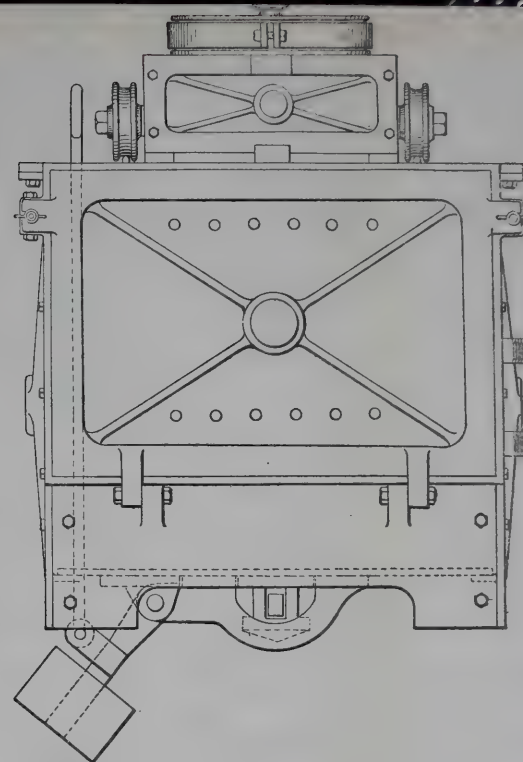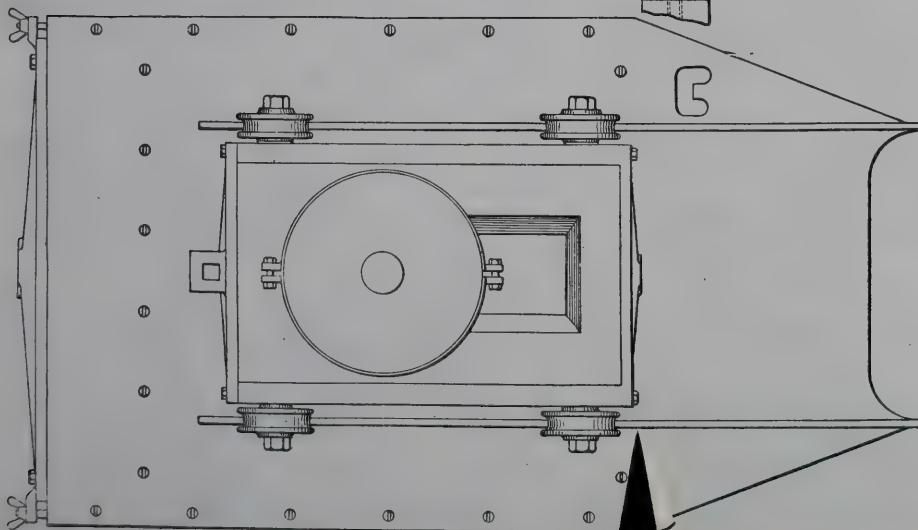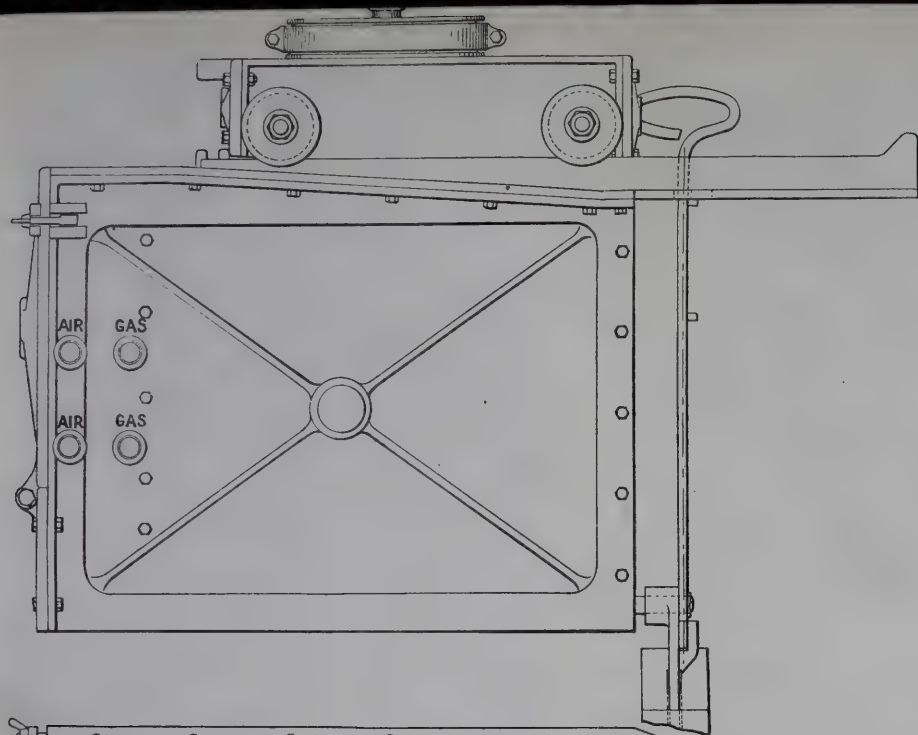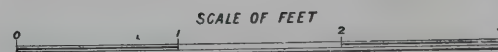
(*f*) Labour charges.

(*g*) Capital charges.

(*h*) Quality of metal produced.

And generally the relative mechanical advantages and disadvantages of the two systems.

(1) *Temperature Attained.*

As is probably well known to members, the temperature at which cupro-nickel must be cast is a critical one and lies within comparatively narrow limits. No difficulty, however, was found in attaining the desired temperature, as a maximum heat of 1400° C. was readily obtained.

The pyrometer used was one designed specially for determining the temperature of molten metal in crucible furnaces. The determination of such temperatures has always been a matter of great difficulty.

The essentials of the pyrometer used were as follows : A fused silica tube, 6 ft. long and $1\frac{1}{2}$ in. diameter, was attached to an iron headpiece containing a convex mirror and thermo-couple, and was connected, as usual, through a millivolt-meter. The silica tube was passed through an asbestos cover, which replaces the ordinary one on a furnace, and carefully heated and pushed down into the molten metal until it was about one-third of the way from the bottom of the crucible. About three minutes was required to attain the maximum steady reading on the instrument.

The life of the silica tube may with care be prolonged to a maximum of thirty immersions, but in some cases very few readings were obtained before the tube failed. Despite this unavoidable expense, in most cases the valuable data obtained compensated the additional cost.

(2*a*) *Cost of Gas compared with Coke.*

The total gas consumption for the entire run was 46,125 c. ft.*
At the current price of gas in Sheffield, 1*s*. 9*d*. per thousand c. ft., this would cost £4 0*s*. 6*d*.

If, however, it were possible to secure gas at the rate allowed

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* The average gas consumption per lb. of metal was 8·07 c. ft.

to users of gas-engines, viz. 1s. 4d., the above figure would be reduced to £3 1s. 6d.

These figures represent respectively 31s. 9d. and 24s. 2d. per ton of metal melted. The average cost of melting over 400 tons of the same alloy in coke-fired furnaces was 36s. 4d. per ton.

(2b) *Speed of Melting.*

In Table II. and Figs. 2 and 3 is shown in detail the average time per heat and gas consumption for each day. The results are intensely interesting, and show that the time required to bring

TABLE II.—*Totals and Averages.*

Day.	Heats.	Total Time (mins.).	Average Time per Heat.	Average Consumption of Gas.
1	6	372	62·0	508
2	9	547	60·8	521
3	9	551	61·2	477
4	12	554	46·2	443
5	8	445	55·6	498
6	9	480	53·3	511
7	11	536	48·7	470
8	10	506	50·6	527
9	10	457	45·7	458
10	12	527	44·0	431
Average for ten days of 96 heats . . .		497·5	51·8	480·5

cupro-nickel to the necessary temperature for casting is much less than in the coke-fired natural draft furnace. Taking the average of the whole of the heats (that is, including the first three heats during which experience was being gained), the averages would be as follows :

Average time of 56-lb. heat in gas furnace . . . 52 minutes
,,   ,,   ,,   ,,   coke furnace . . . 82   ,,

In an ordinary working day of ten hours it is rarely possible to get more than five heats out of a coke-fired furnace, but it will be noticed that on two days during the gas-melting test, twelve heats were secured in less than ten hours. Time is admittedly one of the most important economic factors in the melting of metals, and the above results show a very considerable advantage in the use of gas.

FIG. 2.—Average Gas Consumption per Heat for corresponding Heats. The graph is very similar to that given in Fig. 3, and shows a minimum consumption of 880 c. ft. for the first round (starting at cold) with a drop to 510 ft. for the 2nd round, and gradual fall to the minimum of 390 between the 9th and 12th rounds.
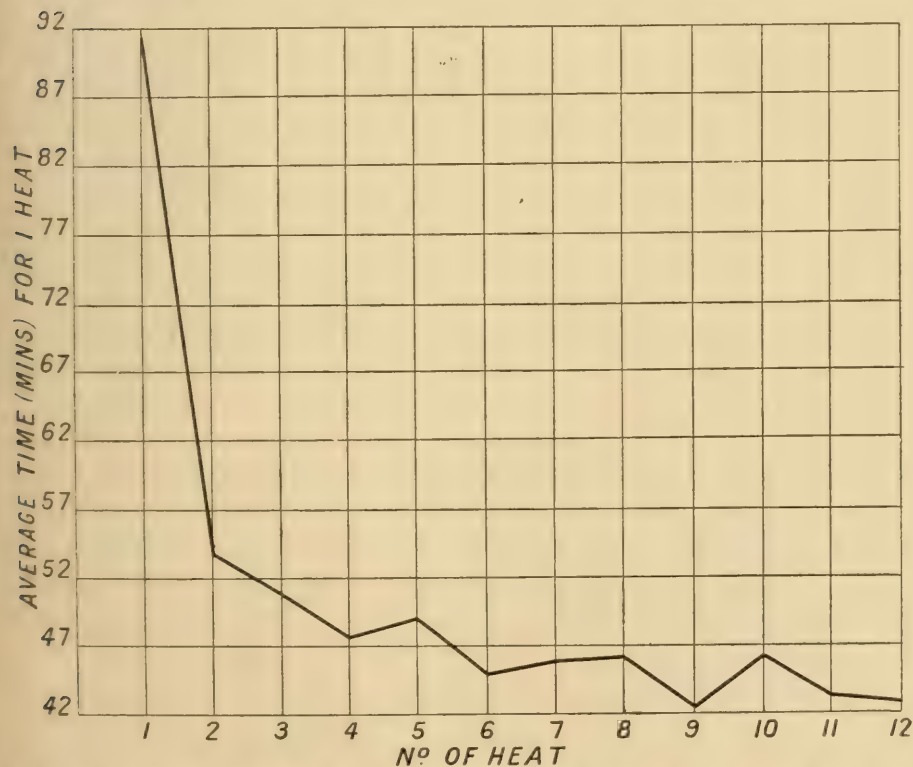
FIG. 3.— Average Time per Heat for corresponding Heats. Showing on the whole a uniform fall with each succeeding heat (starting from cold). The average time of the first round was 91 minutes, with a rapid fall of the 2nd to 53¾, and a decrease down to 42 minutes between the 9th and 12th rounds.

As the test proceeded, the gas consumption and time required for each melt improved. The results in detail and average are shown for the sixth and succeeding days in Tables III. and IV.; and plotted in graphical form in Fig. 4.

TABLE III.—*Gas Consumption.*

Day.	Round 1.	Round 2.	Round 3.	Round 4.	Round 5.	Round 6.	Round 7.	Round 8.	Round 9.	Round 10.	Round 11.	Round 12.
6	1047	471	424	369	521	427	461	469	410	...	...	...
7	762	509	502	417	425	435	449	408	434	435	396	...
8	945	595	586	465	475	462	414	419	428	478	...	...
9	784	529	466	402	445	399	388	367	376	422	...	...
10	760	456	435	381	352	400	373	381	396	506	366	369
Total	4298	2560	2413	2054	2220	2123	2078	2044	2044	1841	762	...
Average	859·3	512·0	482·3	410·4	444·0	424·3	413·3	408·4	408·4	460·1	381·0	...

TABLE IV.—*Time Taken.*

Day.	Round 1.	Round 2.	Round 3.	Round 4.	Round 5.	Round 6.	Round 7.	Round 8.	Round 9.	Round 10.	Round 11.	Round 12.
6	113	45	40	40	60	44	54	43	40	...	...	...
7	78	54	50	42	45	45	48	43	42	47	43	...
8	88	52	54	44	44	50	41	42	45	45	...	...
9	73	51	50	40	45	41	40	35	40	42	...	...
10	73	45	44	40	35	40	38	41	40	50	39	42
Total	435	247	238	206	229	220	221	204	207	165	82	42
Average	87·0	49·4	47·6	41·2	45·8	44·0	44·2	40·8	41·4	41·2	41·0	...

(2c) *Life of Crucible.*

As far as can be gathered from the experience of practical men, one of the greatest disadvantages of the gas furnace is the short life of the plumbago crucible under the "cutting" influence of the flame.

The results of the author's experiments show that the wear and tear on the crucibles is not only contrary to this opinion, but

that the crucibles had a longer average life in the gas-fired than
in the coke-fired furnace.   It was found possible to get as many
as twenty-two heats and an average of 17·6, whereas the life of
the same make of graphite crucible used for this alloy in a coke-
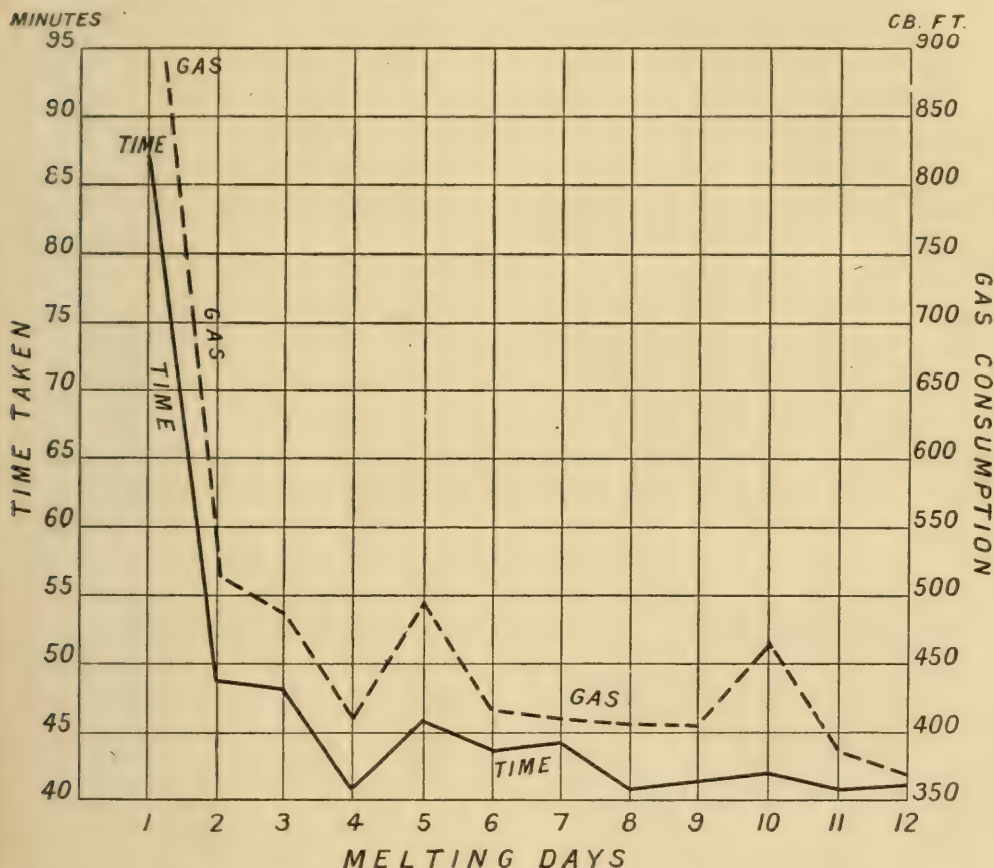
Fig. 4.—Average Gas Consumption and Times. 6th to 10th Days.

fired furnace was found over a period of six months to average
12·5, exceptional crucibles reaching a maximum of sixteen heats.
(See Fig. 5.)

(2d) *Life of the Lining.*

The length of life of the lining of the furnace is one of vital
importance to the manufacturer producing high melting point
alloys, and the writer fully expected to find this one of the weak-
nesses of the furnace.   The results, however, showed that the
lining had stood the test satisfactorily.   The condition of the
burner also was quite good, and no tendency to deterioration was
noticeable.   (See Fig. 6.)

From time to time as it seemed necessary the lining was coated

Fig. 5.—Photo of Crucibles.

over with a wet ganister dressing, just in the same way that coke-
fired furnaces are repaired each week.

(2e) *Mechanical Losses.*

The fact that the crucible in the case of the gas furnace rests

FIG. 6.—Photo of Lining at End of Test.

on a level and the stable base plate, would lead one to expect that
mechanical losses in charging and drawing would be less than in

the case of coke.   The percentage loss was found to be 0·40, and even this would seem to be capable of being still further reduced as the melter gained experience with the furnace.   This represents a substantial saving compared with coke furnaces, as only with the best practice can the loss in the latter be decreased to 1 per cent.

(2f) *Labour Charges.*

On a large installation there would be a distinct advantage in favour of gas in the amount of labour required.   Four coke-fired furnaces can be worked by three men.   It would be possible to work a six-hole gas-fired battery with four men, even taking into account the extra mould preparation incident on the increased speed of gas melting.   This would represent a substantial saving in labour charges.

(2g) *Capital Charges.*

The capital cost (exclusive of the actual building) for installing a battery of gas- or coke-fired furnaces, capable of giving the same output :

> Four pit-fired coke furnaces complete with separate flues and stack, 30 ft. high £280
> Battery of four gas furnaces complete with blower, tank, and gauge, including cost of excavation, would be £242

From these figures it will be seen that there would be very little difference in capital cost.   The above are calculated on present war prices.

(2h) *Quality of Metal produced.*

The working properties of industrial alloys must of necessity be the main consideration from the manufacturer's point of view, and it is very satisfactory to find that the report of one of the largest cartridge factories in the country showed that the material melted in this test was of better quality and resulted in fewer failures than any in previous use.   Up to the final operation of pointing the bullet sheath not a single failure resulted out of the 30,000 cups taken for the test, and only in the last and most drastic operation of pointing was it found that 200 sheaths failed.

This represents 0·6 per cent., whereas the average failures from the best material are not less than 0·8 per cent. It may be added also that, in the opinion of the roller, the material was excellent.

Conclusions.

From the results of the test the following advantages in favour of gas as a fuel may be summarized thus :

1. The absence of dirt and accumulation of ashes.

2. The elimination of the difficult and wasteful process of " slagging."

3. Economy in fuel, in that between the pouring of each heat and the recharging of the pot the gas is cut off.

4. The lining may be easily and even temporarily repaired in the middle of the day's run.

5. The loss of metal resulting from the accidental breaking of the crucible would be far less and more easily recoverable than in the case of metal similarly lost in the coke-fired type.

6. The actual cost of fuel is less when gas was used.

7. The speed of melting is far higher in the gas-fired furnace, and therefore the output over a given period would be substantially greater.

8. The mechanical qualities of the metal were superior to the average coke melted alloy.

9. The deleterious effects of sulphur and oxygen, which however careful one may be, are never absent in the case of coke-melted metal, and are less evident in the case of alloys melted by gas. This is shown by the analyses of the brass in the author's preliminary review, where the sulphur is only a little more than half that recorded for metal melted in the coke-fired type. Since the ideal flame used in the gas-furnace is one only slightly removed from the reducing flame, it may be concluded that oxidation of the metal was reduced to a minimum.

Relative Costs of Meltiny in Different Centres.

Whilst the relative prices of gas and coke vary together, they do not do so always to the same degree in different districts.

The following prices may be taken as the averages in the districts stated. The relative costs of gas and coke melting

are calculated on the figures found for gas and coke melting in the author's tests adjusted for each district :

Town.	Special High Grade Coke, " Metallurgical," " Steel," &c.	Gas (minimum rate per 1000 cubic feet).	Calculated Costs of Melting Cupro-nickel per Ton (based on ruling prices for fuel).	
			Gas.	Coke.
Sheffield .	40s. 3d. per ton	1s. 4d.* 1s. 9d.	24s. 2d. (found) 31s. 9d. ,,	36s. 4d. (found)
Glasgow .	about 40s. per ton	1s. 5d.	25s. 8d. (calculated)	36s. (calculated)
Birmingham	45s. 6d. per ton	1s. 5d.	25s. 8d. ,,	41s. 3d. ,,
London .	50s. ,,	2s. 8d. (Wandsworth, 2s.)	48s. 4d. ,, (34s. 3d.)	45s. 5d. ,, ...

* For use in gas-engines only.

The calorific value of the gas used, based on the average of nine days, was 532 British thermal units (gross).

The cokes used showed on analysis :

	A.	B.
Moisture	0·06	0·59
Ash	7·96	7·02
Volatile matter . .	6·13	3·01
Fixed carbonaceous matter .	85·91	89·81
Sulphur	2·56	1·23

The electrical energy required to run the blower during this test approximated 1s. 8d. per day.

The writer would like to acknowledge his indebtedness to Professor J. O. Arnold, F.R.S., for his valuable help and for granting the author facilities for carrying out the test ; to Mr. A. J. Hartley, to Mr. W. Smith, and others who have so materially helped in the preparation of this paper.

METAL MELTING BY MEANS OF HIGH-PRESSURE GAS.*

By C. M. WALTER, B.Sc. (BIRMINGHAM).

THE application of town's gas for the melting of brasses, bronzes, and other alloys has during the last few years received considerable attention, and at the present time, in many localities where gas can be obtained for this purpose at a reasonably low rate, it is being largely used in this connection with considerable economy in melting costs.

Many excellent types of furnaces are now obtainable from the various firms who specialize in this work, and crucible furnaces having pot capacities from 50 lb. to 800 lb. are now commonly met with. Such furnaces may be classified into three distinct groups, according to the manner in which the gas is applied, as follows :

A. Furnaces designed for working with gas at the ordinary town pressures of 2 to 3 in. water-gauge, and fitted with atmospheric burners.

B. Furnaces employing gas at ordinary town pressures with air under a positive pressure of usually 1 to 3 lb. per square inch.

C. Furnaces in which gas is employed at a pressure considerably higher than the ordinary distribution pressures, and fitted with either—(a) atmospheric burners ; or (b) burners designed for working with air under a moderate pressure of about 20-in. water-gauge.

Furnaces under heading A, in which low-pressure gas and atmospheric burners are employed, are used chiefly in connection with the melting of alloys not requiring a higher temperature than 1100° C., including aluminium alloys, gold alloys, and white metals, pots up to 150 lb. (copper) capacity being employed for this purpose.

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* Presented at Annual General Meeting, London, March 22, 1917.

Under heading B, in which air under a pressure of 1 to 3 lb. per square inch is used, there are the following classes :

1. Pit furnaces and tilting furnaces used for melting brasses, swarf, and scrap, for the production of castings, strip, ingot, and billets, the sizes of crucibles varying from 60 to 800lb. capacity.

2. Furnaces for melting nickel, cupro-nickel, and bronze.

3. Furnaces for melting aluminium alloys and precious metals.

Under heading C there are the following classes :

1. (a) Pit furnaces for melting brasses and bronzes for sand-castings, ranging from 60 to 200 lb. capacity.

2. Pit furnaces for melting brasses, bronzes, and cupro-nickel, for strip and billet castings having pots of capacities up to 200 lb.

3. Pit furnaces for melting aluminium alloys, having pots of capacity 200 to 600 lb. (copper).

4. Small furnaces for melting precious metals having pots of capacity 10 oz. to 200 oz.

1. (b) Furnaces for melting brasses, bronzes, pure nickel, and for melting non-ferrous metals generally where extremely high temperatures and high speeds of melting are required.

In view of the title of this paper, it is to furnaces belonging to Group C, which will be referred to as high-pressure gas furnaces, that I wish to confine my attention, and although each particular type of furnace has its special advantage to meet a particular requirement, from the results of tests recently carried out it would appear that high-pressure furnaces coming under this heading should be capable of meeting all requirements. In the case of the melting of brass in pots of capacity 60 to 200 lb., furnaces fitted with atmospheric injector burners would be used, but where high speed of melting or extremely high temperatures are required, as in the case of melting of pure nickel, furnaces using high-pressure gas with air under a moderate pressure of about 20 in. water-gauge would be employed.

Dealing first with furnaces employing high-pressure gas with atmospheric burners, the following is a description of a standard design of furnace, having a crucible capacity of 60 lb., and suitable for the melting of brasses and bronzes for sand-casting work.

Referring to Fig. 1, which is a sectional elevation of a 60-lb. furnace, it will be seen that the furnace consists of a brick lining, A, built up in sections and having a cylindrical core, B, of a diameter to suit the particular pot used, the whole of the lining being contained in a box constructed of cast iron plates, P, bolted
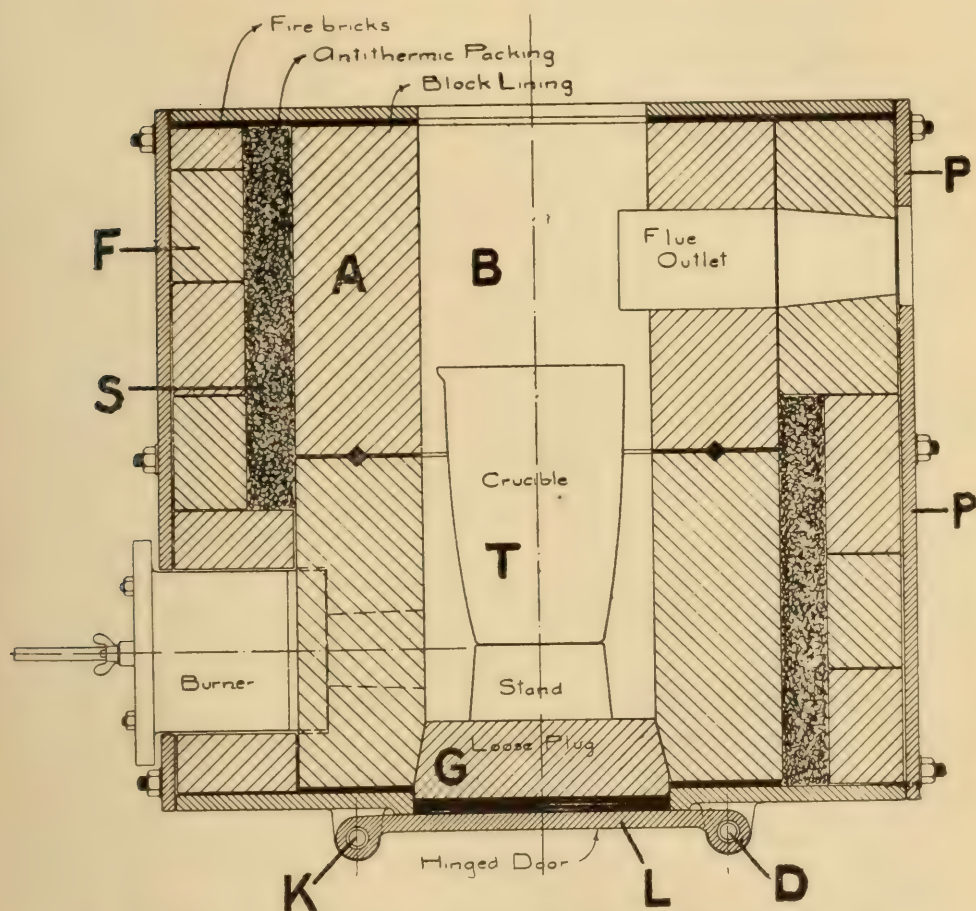
FIG. 1.—Sectional Elevation of 60-lb. Pot Furnace (negative can be supplied).

together loosely so as to allow freedom for expansion and contraction.

The outer case is first lined with a $4\frac{1}{2}$-in. wall of firebrick, F, leaving a space of about 2 in. between the wall and the lining itself, which is packed with non-conducting material, S.

The bottom plate forming the bed of the furnace is supported on brick piers in the furnace pit, leaving a free space of about 10 in. between the bottom plate and the floor of pit, so as to facilitate

the removal of the circular bottom plate, L, which consists of a cast iron flanged plate, having the same diameter as the lining itself, and being held in place by the hinge at K and the drawbar D. On the top of this flange plate the furnace bottom, G, is built, and consists of a mixture of ganister and broken brick, well rammed to a depth of about 3 in., and should it be necessary to remove same for cleaning or removing spilt metal, this can be done in a few minutes by withdrawing the drawbar, D, which causes the lid to fall by its own weight, when the bottom can be knocked out from the top with a dumping rod.

The pot, T, rests on a firebrick stand, thus leaving an annular combustion space between the lining and the pot itself. The dimensioning of this combustion space is of the utmost importance if high temperatures and efficient working are to be obtained, and in the case of furnaces where pots are removed by tongs, only sufficient clearance should be given between the outside of pot and furnace lining, to allow of easy manipulation of the pot tongs. The high-pressure injector burner enters the combustion space tangentially at a point about $\frac{1}{2}$ in. below the bottom of the pot itself, and the flame forms a spiral round the pot, the waste gases passing away into a brick flue fitted with a damper through a nostril arranged about 2 in. above the rim of the pot itself.

Fig. 1A is a sectional plan.

Figs. 2 and 2A represent the general arrangement of furnace pit and flues.

Fig. 3 represents a single high-pressure injector burner, such as would be used on furnaces up to 80 lb. capacity, and which consists of a cast iron thimble carrying a clay injector cone, which fits in a recess moulded in the sectional linings referred to. The burner tubes carrying the jets are supported on cast iron stirrups, slotted so as to allow the jets to be centred with the injector cones. The jet tubes are adjustable axially with reference to the injector cones, the position of the jet with regard to the injector cone depending on the gas pressure employed.

The pressure at which gas is supplied to the jet is usually 11 to 12 lb. per square inch, at which pressure the requisite amount of air for combustion can be injected and a mixture velocity of about 6000 ft. per minute obtained in the injector throat, the actual

velocity of the mixture entering the furnace being about 5000 ft. per minute.

This figure was obtained with a gas of net calorific value of 500 B.T.U.'s per c. ft. (equivalent gross value = 550 B.T.U.'s per c. ft., which value will be used elsewhere throughout this
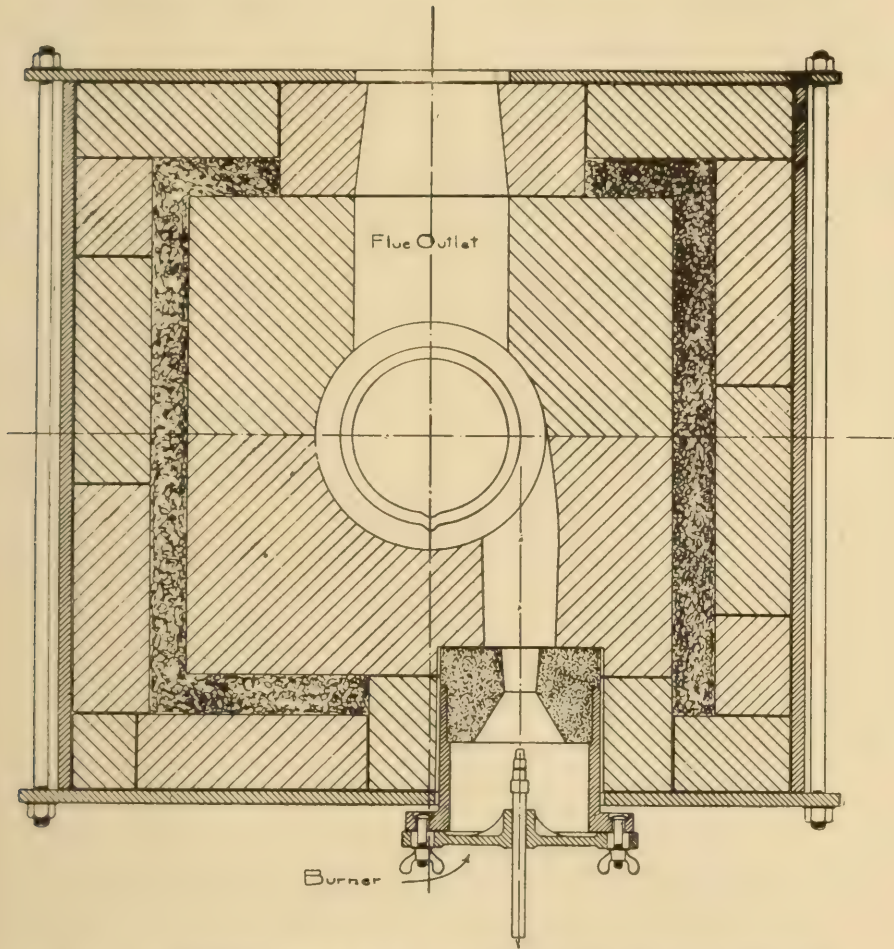
Fig. 1A.—Sectional Plan of 60-lb. Pot Furnace (negative can be supplied).

paper), having a density of 0·52 (air = 1) and requiring 5·5 vols. of air for complete combustion.

Taking the density of the mixture as 0·93 (air = 1), the velocity of the mixture in the throat of the injector cone corresponds to a static pressure of about 2·25 in. water-gauge.

It should be mentioned at this point that, when working with this mixture velocity, the combustion was sufficiently concentrated and flame temperature high enough to meet all the requirements usually met with, temperatures sufficiently high for the melting
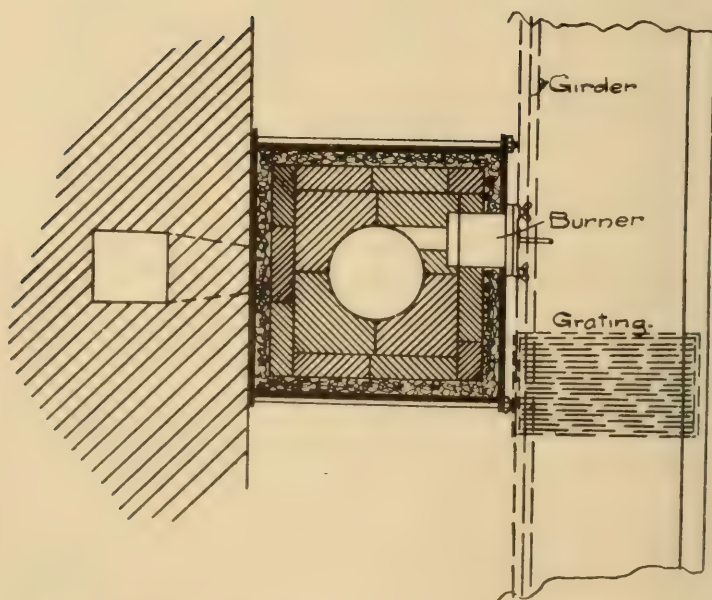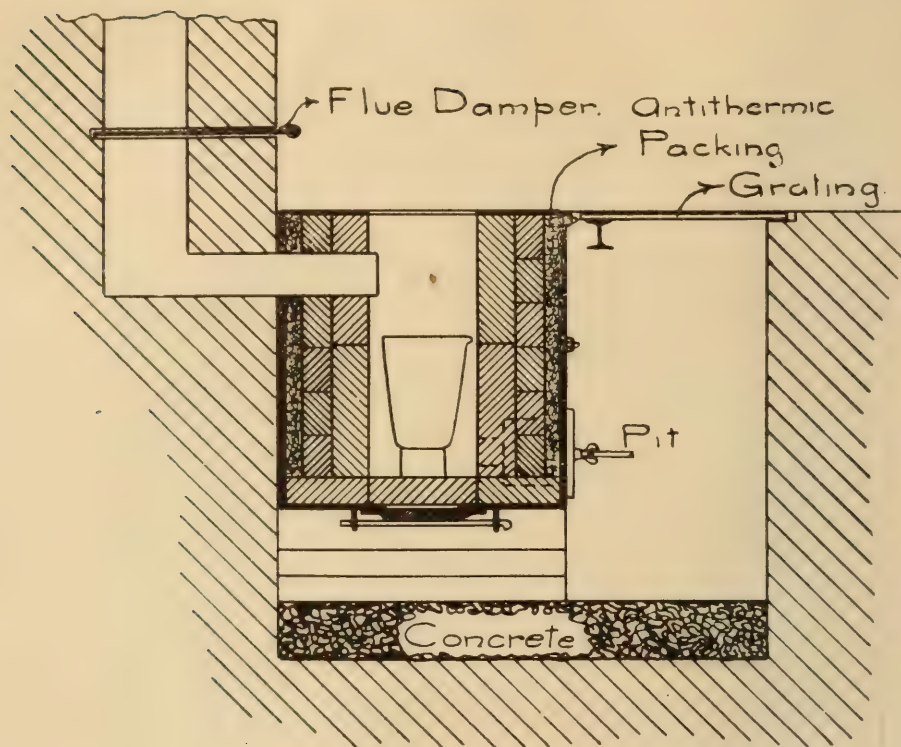
Figs. 2 and 2A.—General arrangement of Furnace Pit and Flues.
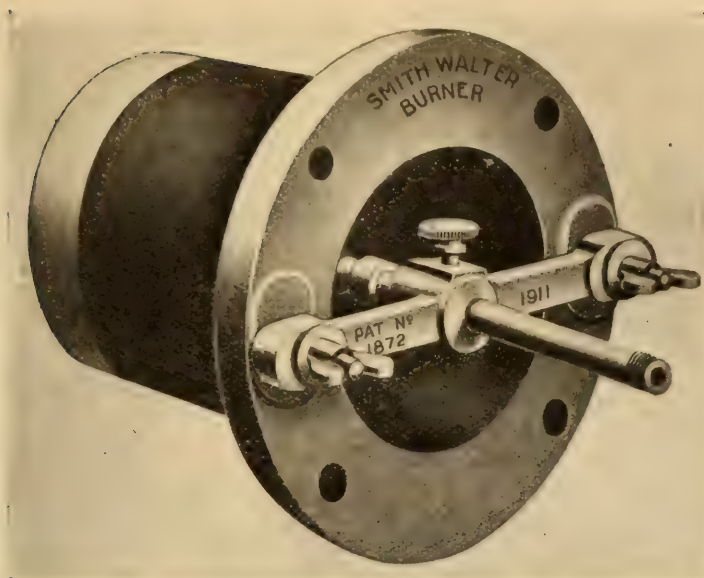
Fig. 3.—Single High-pressure Injector Burner.
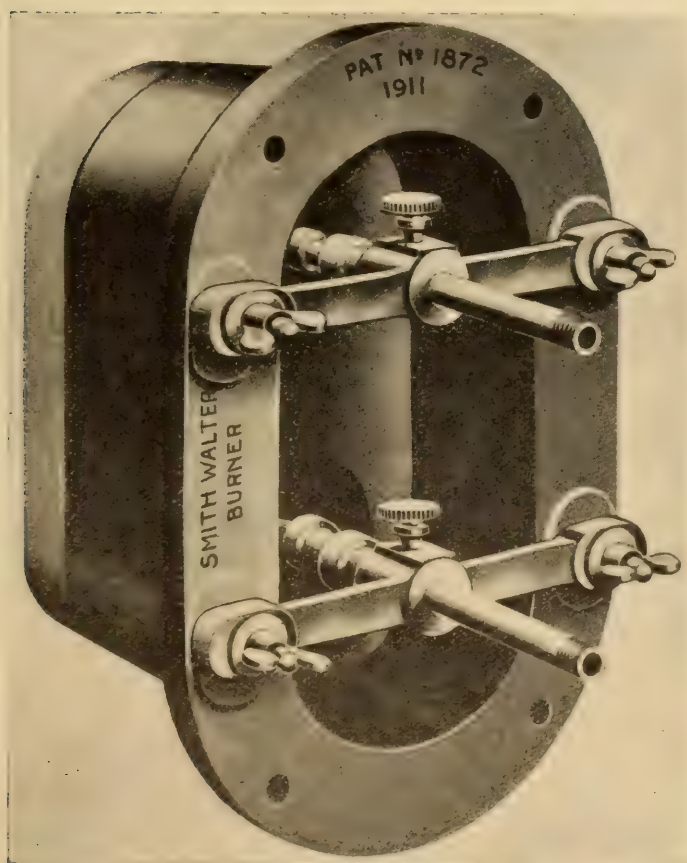
Fig. 3A.—Duplex High-pressure Injector Burner.

of cupro-nickel being obtainable ; but in cases where extremely high speeds of melting are required, the velocity of the mixture entering the furnace may be increased to as much as 9000 ft. per minute with advantage : this applying also where very high temperatures are required, as in the case of the melting of pure nickel. The method by which this increased velocity of the mixture may be obtained will be referred to later, and there will now be given details of costs of melting brass in furnaces as described, the figures given having been obtained from large-scale tests carried out in foundries, and which therefore take into account all the stand-by losses which are met with in actual practice.

The figures of fuel cost given are in most cases based on the actual amount of metal melted, quite irrespective of the amount of castings produced, as it will be understood that any figure based on the castings produced will only be of value if the ratio of the castings produced from a pot of metal to the metal returned in the form of ridges, gits, and runners is known. In some cases these values have been ascertained by actual weighing up the castings, and returns obtained from a heat of metal are given.

In the case of the melting of 60 : 40 brass in 50 to 60 lb. pots for sand-casting, it is found that with gas having a net calorific value of 500 B.T.U.'s per c. ft., 9 to 10 heats of metal can be dealt with in a working day of twelve hours, the first heat usually taking about two hours, whilst second and subsequent heats should be ready for pouring at intervals of about one hour.

For a 60-lb. pot furnace fitted with a single injector burner working with a gas pressure of approximately 12 lb. per square inch, the average gas consumption would be about 280 c. ft. per hour, and the gas per lb. of metal melted (60 : 40 brass) about 5 c. ft. In cases where the stand-by losses are high, owing to the moulds not being ready when the metal is ready for pouring, this figure would be exceeded.

Cost of Furnaces.

The cost of a 60-lb. pot furnace constructed in the manner described, inclusive of excavation and pit work and connections to existing flues, amounts to approximately £25, this figure not including the cost of the running of the gas-supply pipes, whilst in

the case of a similar furnace of 160 lb. capacity the cost would be about £35.

Where two or more such furnaces are installed at the same time, this figure would be slightly reduced.

MAINTENANCE COSTS.

The cost of maintaining such furnaces in a condition such as to give efficient working results will depend on the metal melted and the speed of melting employed, the figures given in Tables I. and II. being those obtained from 60 and 160 lb. furnace installations.

TABLE I.—*Maintenance Cost of 60-lb. High-pressure Gas-heated Brass Melting Furnace as described above, Melting 8 Heats of Metal per Day.*

Average life of furnace lining = 12 months.

	£	s.	d.
Cost of re-lining	3	0	0
Cost of patching-up, re-bottoming each week for twelve months .	5	0	0
Burner cone replacements for twelve months' working (1 set) .	0	5	0
Total cost	£8	5	0

Total metal melted = approx. 60 tons.
Maintenance cost per cwt. metal melted = 1·65d.

TABLE II.—*Maintenance Cost of 130-lb. High-pressure Gas-heated Brass Melting Furnace as described above, but with Rammed Ganister Inner Lining, Melting 10 Heats per Day.*

Average life of furnace lining = 6 months.

	Cost per Annum.		
	£	s.	d.
Cost of re-lining ($\frac{1}{2}$ ton ganister, £1).	2	0	0
,, ,, (labour, 11s. 8d.)	1	3	4
Cost of patching-up and re-bottoming each week for twelve months	5	7	0
Burner cone replacements for twelve months' working (4 sets) ,	1	0	0
Total cost	£9	10	4

Total metal melted = approx. 160 tons.
Maintenance cost per cwt. metal melted = 0·7d.

LIFE OF POTS.

The pot costs vary considerably with each installation, according to the conditions of working. In the case of 60-lb. pots, it is found from tests extending over a considerable period that a good average working figure may be taken as 30 heats per

pot in the case of furnaces used for producing sand-castings, where 8 to 10 heats per day are the maximum number required, but where the speed of working can be increased it is found that the number of heats per pot obtainable can be increased almost in the same proportion, which can be explained from the following observations.

The pot life is largely dependent upon :

1. Nature of metal melted.
2. The speed of melting.
3. The period between heats during which the pot is allowed to cool.
4. The temperatures which are employed.

Generally speaking, where high temperatures are employed and the speed of melting is high, the pot costs are lower per cwt. metal melted than when the reverse is the case, this being undoubtedly due to :

(i.) The higher temperature produces on the outside surface of the pot a protective glaze.

(ii.) The temperature changes of the material of which the pot is composed are reduced to a minimum when speed of working is a maximum.

In the case of the melting of borings or swarf, where the metal requires a large amount of puddling, the pot life is considerably reduced, owing to the mechanical wear on the pot which takes place.

Where the speed of melting can be increased from 8 to 12 heats per day, it is found in some cases that the life of the pot can be increased to about 40 heats.

In the case of strip and billet casting in pots of 130 to 200 lb. capacity melting 10 heats per day, the average life of a pot is found to be about 26 heats, this figure being slightly higher in the case of the smaller pots, and slightly lower in the case of the larger pots.

Fig. 4 is a sectional elevation of a 160-lb. furnace built up in a cylindrical wrought iron case, and so arranged that the bottom half section of the lining can be replaced without disturbing the upper portion.

It will be noted that two double jet burners are employed, entering the combustion space tangentially from opposite sides,

this being the usual burner arrangement for furnaces having pot
capacities greater than 100 lb.
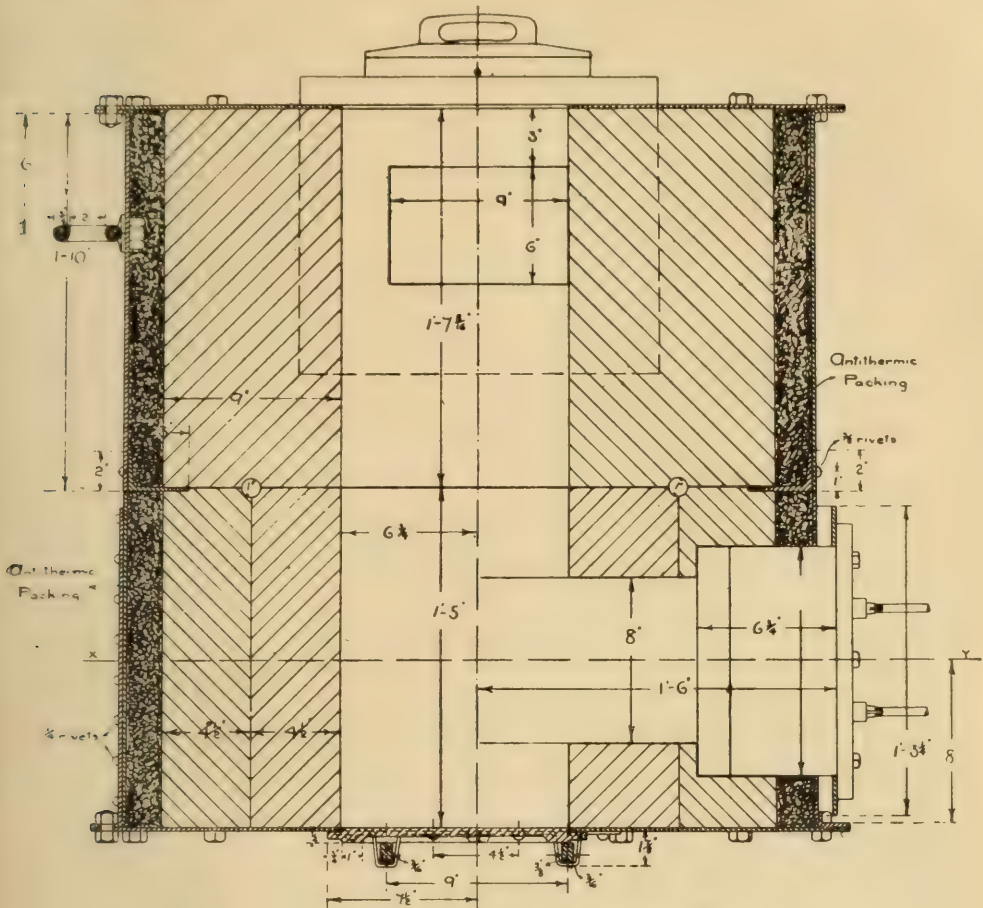
FIG. 4.—Sectional Elevation of 160-lb. Pot Furnace.

METAL LOSSES.

The loss of metal during metal melting is a subject which
should receive the most careful attention, especially when it is
remembered that the value of the metal lost in such operations
amounts, in some cases, to considerably more than the total fuel
cost of melting.

It often happens that whilst every attempt is made to reduce
the latter cost to the lowest possible figure, the effect of the
various systems of heating employed on the former figure are
overlooked. In comparing, therefore, the relative melting
efficiencies of various types of furnace plant, this question of
metal loss should receive full consideration. It is in this con·

nection that very considerable economies have been obtained in the melting of brass with gas-heated furnaces, and if the value of the metal lost during the process of melting be considered as a melting cost, which in reality it is, it will be found in many cases that where high-pressure gas furnaces are employed, as compared with melting by coke in ordinary pit furnaces, the economies effected owing to the reduction in metal losses alone more than outweigh the extra fuel cost involved ; this may be explained as follows.

The metal lost during the melting of brass consists of :

1. Spelter which has been volatilized and carried off with the waste gases.
2. Metal which has been oxidized to form a dross.
3. Metal which is spilt over the sides of pot.

The losses under (1) and (2), so far as the brassfounder is concerned, may be considered as non-recoverable, and under (3) as partially recoverable.

In order to reduce these losses to a minimum, in the first place the regulation of the temperature should be under complete control, so as to prevent overheating of the metal and the consequent loss of spelter ; secondly, the atmosphere in contact with the surface of the metal should be non-oxidizing, and if possible slightly reducing in order to prevent the formation of dross ; thirdly, the design of the furnace itself should be such that any metal spilt over the sides of the pot is easily recoverable.

The desiderata referred to above can be obtained only to a limited degree in the case of the coke-heated furnace by reason of its design and principle of working ; but, as will be easily understood, in the case of the gas-heated furnace these requirements are easily obtainable, the regulation of temperature being under complete control, the atmosphere in contact with the surface of the metal being non-oxidizing, whilst any metal spilt over the side of the pot is directly recoverable by the removal of the bottom plate from the furnace. Mention should be made, however, at this point that in order to obtain the best results the bottom of the furnace should be taken out periodically for the removal of spilt metal. Dampers should be fitted to all take-off flues, and the regulation of these should be such that the waste gases leave the

furnace under a slight pressure, in order to ensure a reducing atmosphere on the surface of the metal in the pot.

Coming to the actual metal loss, it is usual for these figures to be given in pounds of metal per cwt. of castings produced, and although such figures signify all that is required for a particular class of work, nevertheless, for purposes of comparison, they are of little value, as they do not constitute any basis on which the loss per cwt. of metal melted can be computed.

For comparative purposes it has therefore been found desirable to take as a basis the figure of loss of metal on the actual metal melted for a given process, assuming that the whole of this metal less the loss obtained is converted into castings, billets, or strip as the case may be, which figure when multiplied by the ratio

$$\left(1 + \frac{\text{weight of returns}}{\text{weight of castings produced}}\right)$$ gives the approximate figure

of loss for any particular class of work for which the ratio mentioned is known : the ratio really representing the number of times a given quantity of metal has to be re-melted to convert same into castings.

It will be noted that this approximation assumes the loss on the re-melted returns, consisting of ridges and gits, to be the same as in the case of the original metal from which they were produced, which is found to be sufficiently near for all practical purposes.

In Table III. are given values of metal losses obtained for different classes of work when melting by means of high-pressure gas, the ratio given above being referred to as R.

TABLE III.—*Figures of Metal Loss obtained when Melting with High-pressure Gas Furnaces.*

1. Metal Melted.	2. Work Produced.	3. R. = 1 + wt. of returns wt. of castings produced	4. Loss per Cent. on Metal Melted.	5. Loss per Cent. on Work Produced.	6. Capacity of Furnace used in Pounds.
$\frac{62}{38}$ brass	Very light cored castings	2·0	2·05	4·1	60
$\frac{60}{40}$ brass	Medium cored castings .	1·5	2·20	3·3	60
,, ,,	,, ,, ,,	1·6	2·18	3·5	60
$\frac{60}{40}$ brass	Billets	1·18	1·52	1·8	130
$\frac{72}{28}$ brass	Strip	1·05	0·56	0·59	160

The percentage loss figures given in column (5) are those actually obtained from tests, and represent the loss of metal on the castings, &c., produced, whilst the figures given in column (4) represent the loss of metal on the metal required to be melted to produce these castings, as computed from the ratio factors given.

Comparing these losses with those which obtain when melting by coke, figures obtained from various installations of 60 lb. coke-heated pit furnaces show that in the case of the melting of 60 : 40 brass for sand-castings the losses usually amount to 6 to 7 lb. per cwt. of castings produced, as compared with 3 to 4 lb. in the case of gas. In taking into account the saving effected by a reduction in the metal losses, it should be remembered that any metal saved appears as castings, strip, or billet, as the case may be, and its value in this condition must be that which is taken into account.

TABLE IV.—*Record of a Test on Twelve 50-lb. High-pressure Gas Brass Melting Furnaces.*

Foundry test on twelve 50-lb. brass melting furnaces.   (High-pressure gas.)

Meter at commencement	11,371,700 c. ft.
,, ,, finish	11,400,220 ,,
Weight of metal per heat	50 lb.

Summary.

Total number of heats (twelve furnaces)	75
Total weight of metal melted (average 50 lb. per heat) (1 ton 13 cwt. 1 qr. 26 lb.).	3750 lb.
Total gas consumption for the day	28,520 c. ft.
Average gas consumption per heat	380 ,,
,, ,, ,, ,, cwt.	851 ,,
,, ,, ,, ,, lb. of metal melted . .	7·6 ,,

Table IV. is a summary of the results of a day's test carried out in a foundry where twelve 50-lb. pot furnaces are employed for the production of light and medium cored work. Although the figures of melting cost are considerably higher than would have been the case had the furnaces been working up to their maximum melting capacity, nevertheless the conditions of working are representative of what might be expected in an ordinary foundry, where, owing to the nature and variety of the work dealt with, the stand-by losses must be necessarily higher than in the case of repetition work where moulding machines would be employed. Full details of this test have been lodged with the Secretary for inspection.

The plant referred to had been working daily for twelve

months prior to the tests being made, and with the exception of one furnace, no linings had been replaced. Further, other tests carried out showed that a figure of gas consumption of 4·5 c. ft. per lb. of metal melted could be obtained when the furnaces were melting up to their full capacity.

TABLE V.—*Summary of Results of Tests on Melting Cupro-nickel in 130-lb. High-pressure Gas-heated Furnace.*

Summary of Tests on Cupro-nickel Melting.
Furnace was a 130-lb. crucible furnace.
Gas calculated at 1s. 3d. per 1000 c. ft.
Consumption, 495 c. ft. per hour.

Average gas consumption per 84 lb. melted .	.	.	.	792 c. ft.
,, ,, ,, ,, 112 lb. ,,	.	.	.	1057 ,,
,, ,, cost per cwt. melted .	.	.	.	15·8d.
,, ,, cost per ton melted .	.	.	.	£1 6s. 3½d.
,, ,, consumption per lb. melted	.	.	.	9·4 c. ft.

Table V. gives a summary of the results of tests carried out in connection with the melting of 80 : 20 cupro-nickel in a 130-lb. high-pressure gas-heated pit furnace, during which thirteen 84-lb. heats of metal were melted, the average gas rate per hour being 495 c. ft., and the average gas consumption per heat being 792 c. ft., corresponding to 9·4 c. ft. per lb. of metal melted.

TABLE VI.—*Record of Test on Melting of 72 : 28 Cartridge Metal in 160-lb. High-pressure Gas Furnace.*

No. of Heats.	Consumption of Gas in C. Ft.	Weight of Metal.	Cost of Melting per Cwt.	Consumption of Gas per Hour.		Length of Day.	
		Lb.	Pence.	C. Ft.	Over.	Hrs.	Min.
4	4,670	672	11·6	557	,,	8	23
5	5,400	840	10·8	666	,,	8	6
5	5,000	840	10·0	689	,,	7	15
6	5,900	1,008	9·8	690	,,	8	33
6	5,600	1,008	9·3	660	,,	8	29
5	5,700	840	11·4	712	,,	8	0
6	5,900	1,008	9·8	696	,,	8	43
6	6,150	1,008	10·2	696	,.	8	50
6	6,190	1,008	10·3	687	,,	9	0
6	6,089	1,008	10·1	688	,	8	54
5	4,950	840	9·9	571	,,	8	40
5	5,800	840	11·6	696	,,	8	20
6	6,000	1,008	10·0	666	,,	9	0
4	4,830	672	12·2	703	,,	6	52
75	78,179 (Total)	12,600 (Total)	10·5 (Average)	669 (Average)		...	...

Five pots were used. Heats from each
$$\begin{cases} \text{No. 1 (old pot)} & . & . & 4 \\ \text{,, 2 (new pot)} & . & . & 10 \\ \text{,, 3 ,, ,,} & . & . & 17 \\ \text{,, 4 ,, ,,} & . & . & 21 \\ \text{,, 5 ,, ,,} & . & . & 24 \end{cases}$$

Average consumption of gas per heat (168 lb.) . . . 1042 c. ft.
,,   ,,   ,, ,, ,, hour . . . . . 670 ,,
,,   cost of melting per cwt.   . . . . . 10·52 pence.

Losses :
	Cwt.	Qr.	Lb.
Total metal produced	106	1	9
Returns, *i.e.* spillings	0	1	19
Losses	0	2	15¾
Metal recovered from bottom of furnace	0	1	10¼
Total metal melted, *i.e.* included in heats.	107	2	26

Percentage loss   . . . . 0·59 per cent.
Average gas consumption per lb. metal melted . . 6·2 c. ft.

Metal sent in :
	Lb.
75 heats, 160 lb. each	12,000
Extra scrap	66
	12,066

Table VI. gives the results obtained from tests carried out in connection with the melting of 72 : 28 cartridge metal. The total metal weighed in consisted of 75 heats, each of 160 lb., with 66 lb. extra scrap, the charge consisting of ingot, copper, spelter, and scrap.

The heats were made up to 168 lb. in each case by the addition of extra scrap and clean spillings from the previous heat, with the result that the total quantity of metal actually melted amounted to 12,600 lb.

The average consumption of gas per heat of 168 lb. amounted to 1042 c. ft., which is equivalent to 6·2 c. ft. of gas per lb. of metal melted. The average loss amounted to 0·59 per cent.

Fig. 5 is a photograph of a battery of twelve 160-lb. high-pressure gas-heated pit furnaces used in connection with the melting of brass for the production of 100-lb. billets. In this installation the gas is taken from the main at ordinary town pressure, and compressed up to a pressure of 12 lb. per square inch on the premises.

Fig. 6 is a diagrammatic sketch of the compressing plant used for this purpose, and will be referred to later.
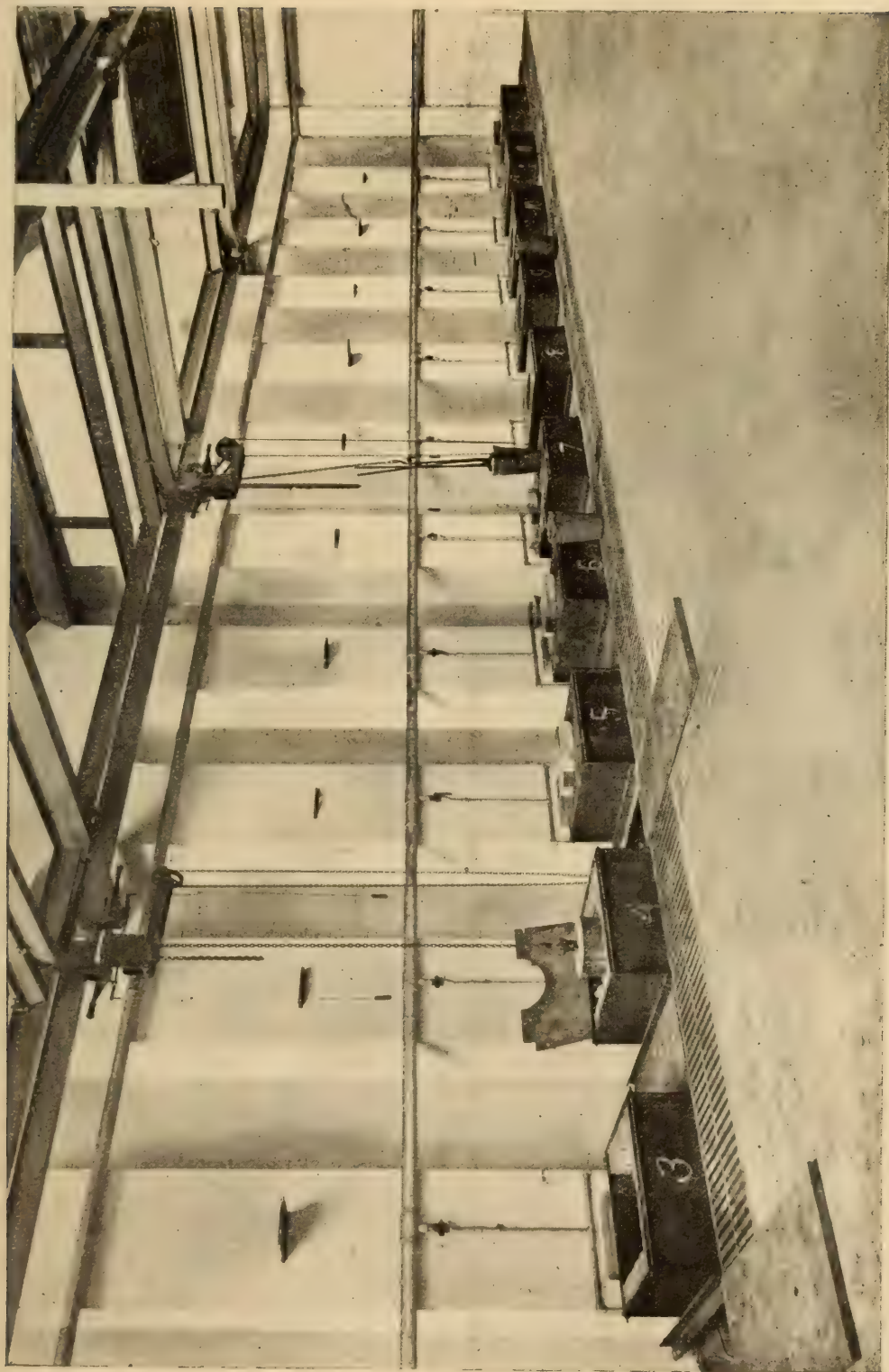
Fig. 5.—Installation of Twelve 160-lb. High-pressure Gas Furnaces for Billet Casting.
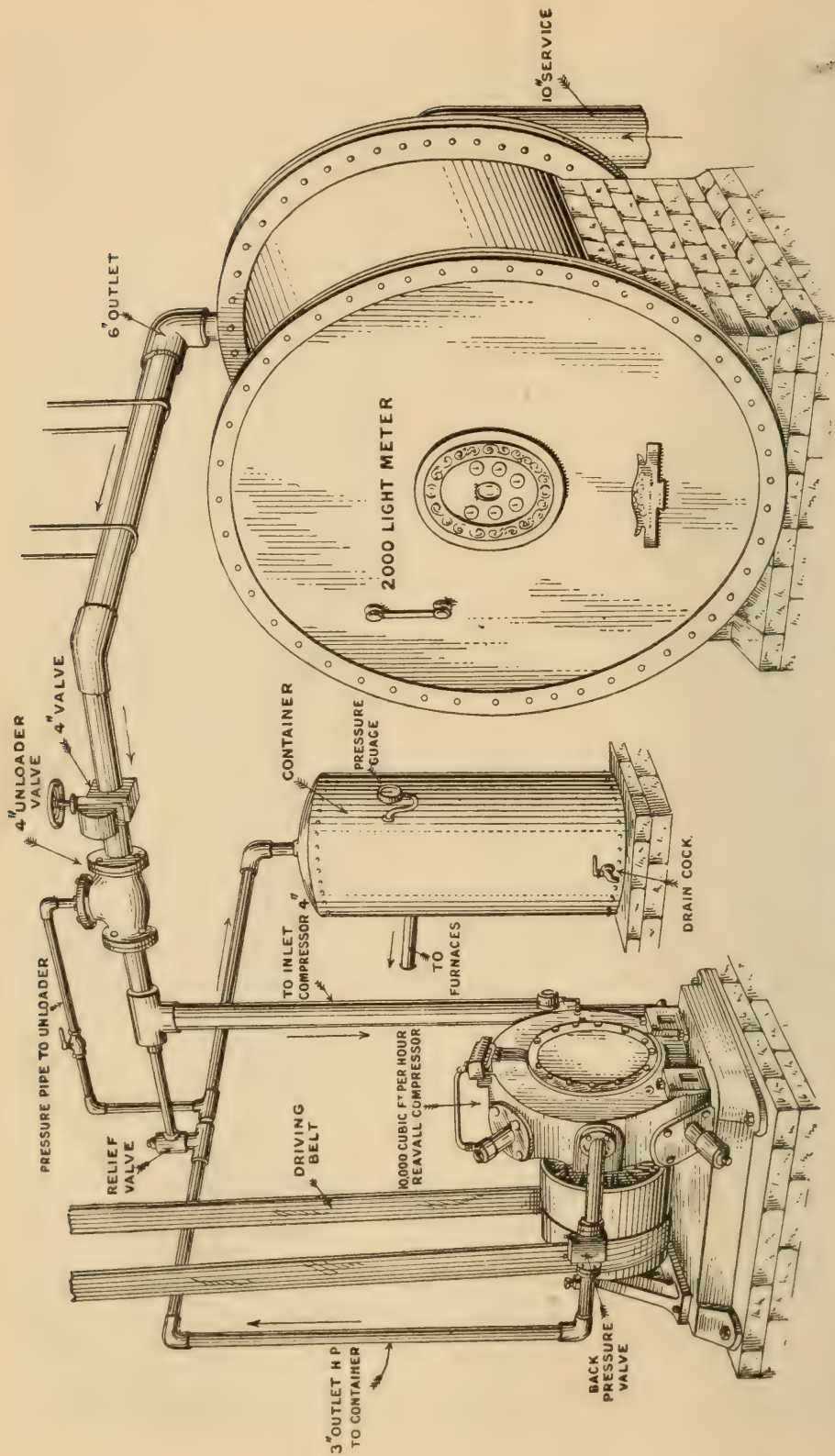
Fig. 6.—Diagrammatic Sketch of Gas-compressing Plant.

TABLE VII.—*Summary of Results of Twelve Months' Working with Twelve 160-lb. Furnaces for Billet Work.*

No. of furnaces installed 12
No. of furnaces used at one time 8
Capacity of pots . . . . 130 lb.

Meter reading, Dec. 29, 1916 14,768,900
    ,,   ,,   Jan. 21, 1916 426,400

    Total gas used 14,342,500

Total metal melted . . . . . . 1086 tons.
    ,,   ,,   ,, ... 2,432,640 lb.

Gas used per lb. metal melted . . . . $\frac{14,342,500}{2,432,640} = 5.9$ c. ft.
Average life of pots = 28 heats of 110 lb.

Maintenance Costs per Furnace per Annum.

Cost of fettling and re-bottoming £5 7 0
Cost of re-lining with rammed ganister twice per year :
    1 ton ganister £2 0 0
    Labour 1 3 4
                                       3 3 4
Burner cone replacements (4 sets) at 5s. per set 1 0 0
    Total maintenance cost £9 10 4

    Total metal melted per furnace per annum = approx. 160 tons.
    Maintenance of cost per cwt. metal melted = 0.7*d.*

Table VII. is a summary of the results obtained with the melting plant referred to taken over twelve months' working.

TABLE VIII.—*Summary of Results of Twelve Months' Working with Two 60-lb. and One 160-lb. High-pressure Gas Furnaces.*

Two furnaces used :
    One 60-lb. pit furnace for sand-casting.
    One 160-lb. furnace for metal mixing and running down scrap.
Metal melted = 62 : 38 brass.
                                         Lb.
Total finished castings produced 58,683
Ingot metal produced from scrap and new metal . . . 32,595

    Total ingot and castings produced 91,278

Ratio factor : $1 + \dfrac{\text{weight of returns}}{\text{weight of castings produced}} = 1.55$

Total gas used . . . . 1,103,210 c. ft.
Gas per lb. of castings produced . . . . . 12.00 ,,
Average pot life . . . . 30 heats
Average loss of metal on castings produced . . . 4.1 per cent.
Average loss of metal on metal melted . . . . 2.6 ,,
Total maintenance cost of linings (3 furnaces) . . £12 13s. 7d.

Table VIII. is a summary of the results obtained in the case of a small plant consisting of two 60-lb. high-pressure gas pot furnaces for sand-casting, and one 160-lb. furnace for metal mixing and scrap melting, the gas in this case being compressed

on the premises ; and owing to the whole of the gas for both the large and small furnaces being registered by one meter, it is impossible to give a dissection of the amount of gas used for each particular process.

The results of a large number of tests show that, in the case of the melting of brass of approximate composition 60 : 40 in high-pressure gas furnaces, the gas consumption allowing for all stand-by losses amounts to approximately 6 c. ft. per lb. of metal melted in the case of ingot, strip, and billet work, the metal loss in this case being about 1·8 per cent. of the metal melted ; and to 12 c. ft. per lb. of castings produced in the case of medium and light cored castings, the loss in this case amounting to about 4 per cent. of the metal melted.

TABLE IX.—*Comparative Furnace Costs of Melting* 60 : 40 *Brass in Coke and High-pressure Gas Furnaces in* 60-*lb. Pots for Sand-castings.*

Costs per Cwt. Castings produced (R. = 2).	
With High-pressure Gas of Calorific Value = 500 B.T.U.'s net,* at 1s. 6d. per 1000 C. Ft.	With Coke at 25s. per Ton.
Fuel cost. 　Taking 12 c. ft. gas per lb. castings 　　produced . . . . . 24·0	Taking 1 cwt. of coke per cwt. 　castings produced . . . 15·0
Pot cost. 　Taking life as 30 heats per pot . 8·0	Taking life as 30 heats per pot . 8·0
Maintenance and repairs. 　Re-bottoming each week, and re- 　　lining once each year . . . 1·65	Fettling each week, and rebuild- 　ing once each year . . . 2·04
Interest on capital outlay. 　At 5 per cent. per annum, taking 　　cost £25 per furnace . . . 0·50	At 5 per cent. per annum, taking 　cost £10 per furnace . . 0·20
Depreciation. 　Taking life as being ten years . . 1·00	Taking life as being ten years . 0·40
Value of metal loss. 　Taking this as being 4 lb. and equal 　　to value of castings at, say, 10d. 　　per lb. . . . . . 40·00	Taking this as 6 lb. at 10d. per lb. . 60·00
	Cartage of ashes . . . 0·50
Total costs . . . . 75·15	Total costs . . . 86·14

Note.—From the above it will be seen that with gas at 1s. 10d. per 1000 c. ft. and coke at 15s. 6d. per ton delivered, the furnace costs would be about equal.

* Equivalent to approx. 550 B.T.U.'s (gross).

Table IX. gives the comparative costs of melting brass by high-pressure gas and coke for the production of medium sand-castings, where the weight of castings produced is approximately equal to the weight of the returns (ridges and gits), the costs given being the costs per cwt. of castings produced in each case.

Melting of Aluminium in High-pressure Gas Furnaces.

An equally important application of the use of high-pressure gas is in connection with the melting of aluminium and aluminium alloys, and for the production of fine quality castings and high tensile alloys of this metal, owing to the cleanliness, convenience, and ease of temperature control, the high-pressure gas furnace may be said to have firmly established itself in this connection on the score of both efficiency and economy.

For the melting of such alloys on a large scale, the furnace usually employed is one constructed on similar lines to those already described, heated by means of high-pressure injector burners, with gas at a working pressure of about 12 lb. per square inch.

These furnaces are usually built to take pots of capacity 500 to 600 lb. (copper), the metal being ladled from the melting-pots into smaller pots for carrying to the moulds. With such plant it is found that, in the case of the melting of the ordinary commercial aluminium alloys, during a working day of twelve hours, 10 heats of metal of about 200 lb. each can be obtained from each furnace, with a gas consumption of 12,000 to 14,000 c. ft. per ton of metal melted.

Fig. 7 represents a battery of six such furnaces having pot capacities of 600 lb. (copper). When working under the conditions mentioned above, the pot life is found to average twenty-five days' work, with a corresponding pot cost of approximately 1·6 pence per cwt. metal melted. The life of linings, in the case of a very large installation, in which over thirty such furnaces have been in continuous use for upwards of five years, approximated to three years' work, allowing for patching-up at the end of each week.

It may be interesting to note that one firm alone, in Birmingham, is taking as much as 25,000 c. ft. of high-pressure gas
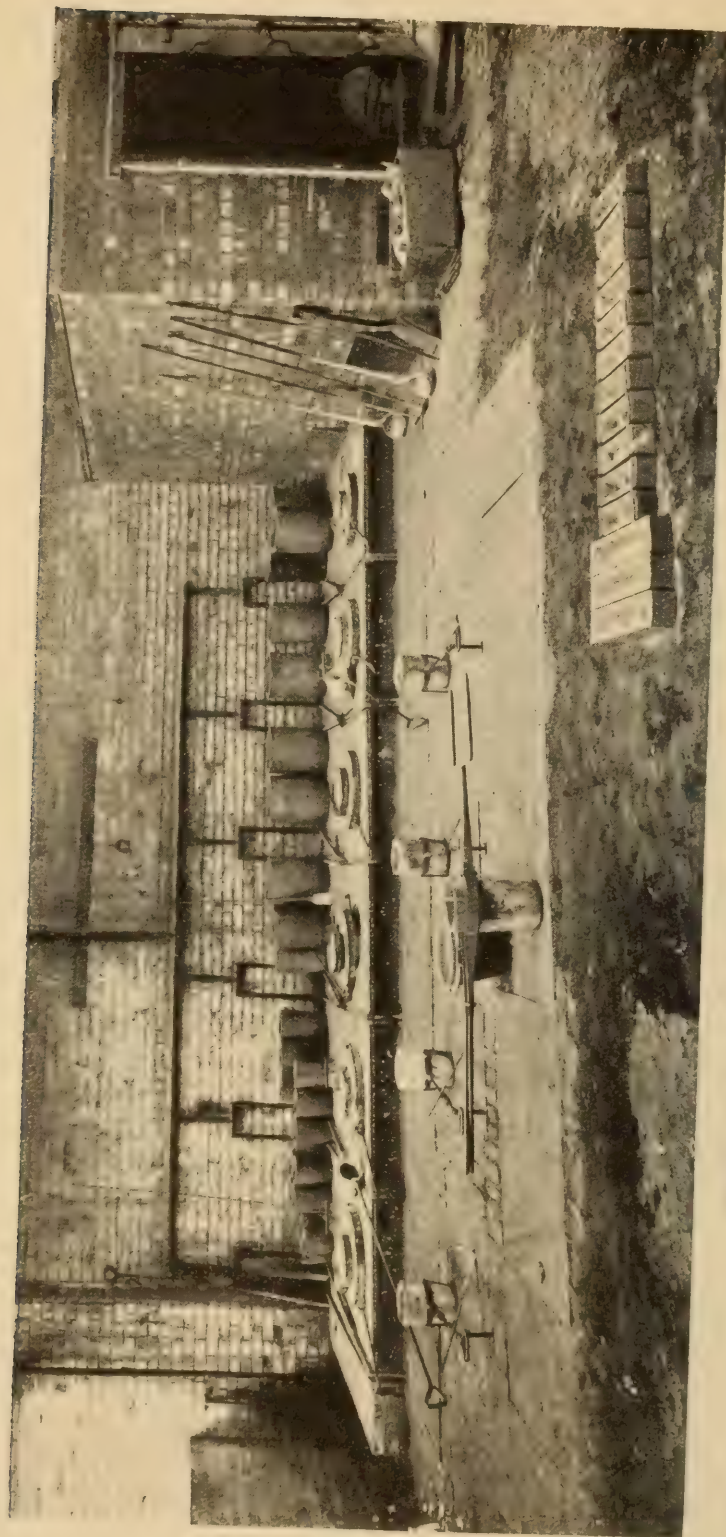
FIG. 7.—Battery of Six 600-lb. (copper capacity) Aluminium Melting Furnaces.

per hour, continuously, for melting aluminium alloys, over sixty furnaces being used in this one installation.

General Notes.

In all the plant referred to above, the figures of gas consumption and cost of melting are based on the gas used having a net calorific value of 500 B.T.U.'s per c. ft.* and being supplied at a working pressure of 10 to 12 lb. per square inch, this pressure being found to be necessary where injector burners are employed if high efficiencies are to be obtained.

The advantages to be derived from the use of the injector burner will be at once apparent, when it is remembered that such a burner is to a great extent automatic in its action of providing the necessary air for the complete combustion of the gas used over a wide range of gas consumption, and at the same time is self-compensating for slight variations which may take place in the gas supply pressure, the amount of air injected being proportionally greater or less, according as the pressure rises or falls within such limits as would be ordinarily met with.

Further, the simplicity of control by one tap eliminates errors which are likely to occur where both air and gas are used, the latter system necessitating readjustment of mixture from time to time if efficient results are to be obtained.

Many advantages gained by the use of gas as a fuel, as compared with coke, have not been taken into account in the figures of cost given above, owing to the difficulty of assigning a correct value for the advantages so gained ; but as such advantages, due to cleanliness, convenience, and ease of manipulation, must necessarily reduce the labour costs involved in any melting operation, they should not be overlooked when comparing such a system with one in which solid fuel is employed.

Gas-compressing Plant.

It will be noted that, in the case of the figures of fuel cost given in the various tables above, no mention has been made of the costs of compressing the gas used, owing to, in the majority of the cases

* Equivalent gross value = 550 B.T.U.'s per c. ft.

referred to, the gas being supplied direct from a high-pressure gas main at the full working pressure.

In Birmingham some 24 miles of mains carrying gas at a pressure of about 12 lb. per square inch form part of the distributory system, and in cases where manufacturers have their premises situated on the line of route of these mains they are able to obtain a supply of gas at this pressure, special meters having been designed for use in such cases, which automatically correct in their registering the actual volume of gas used under the particular working pressure, to the equivalent volume of gas if measured at ordinary town pressures.

Where, however, consumers requiring high-pressure gas are not in a position to obtain such a supply direct from the main, it becomes necessary for gas-compressing plant to be installed on the consumers' premises, and in such cases the type of plant used will depend upon the pressure which is required. If the pressure required does not exceed 5 lb. per square inch, rotary type machines can be used ; but in the case of higher pressures, compressors of the reciprocating type must be employed.

Referring to Fig. 6, which represents diagrammatically the general arrangement of a compressing plant capable of dealing with 10,000 c. ft. of free gas per hour, and delivering same at a pressure of about 12 lb. per square inch, it will be noted that the low-pressure supply to the meter passes through a 10-in. pipe, whilst after compression a 3-in. pipe is sufficient to convey the same volume of gas to the point of combustion.

The gas entering the inlet of the compressor is controlled by means of an apparatus known as an Unloader, which is fixed to the inlet side of the machine, and consists of a piston operated valve controlled by the working pressure on the outlet of the machine, and so arranged that the amount of gas admitted to the compressor corresponds with that used on the outlet, so that the power taken to drive the compressor is approximately proportional to the amount of gas used, and moreover a constant supply pressure on the outlet of the machine is maintained.

Fig. 8 gives details of the construction of such a valve designed by the author to meet this requirement.

The author would specially emphasize the importance of employing such a system of control, in favour of the usual form of

by-pass valve, where the gas which is not used on the outlet of the machine is by-passed back on to the inlet ; in which case the machine is running at full load the whole of its time, and is taking the most power to drive it when delivering the least quantity of gas.
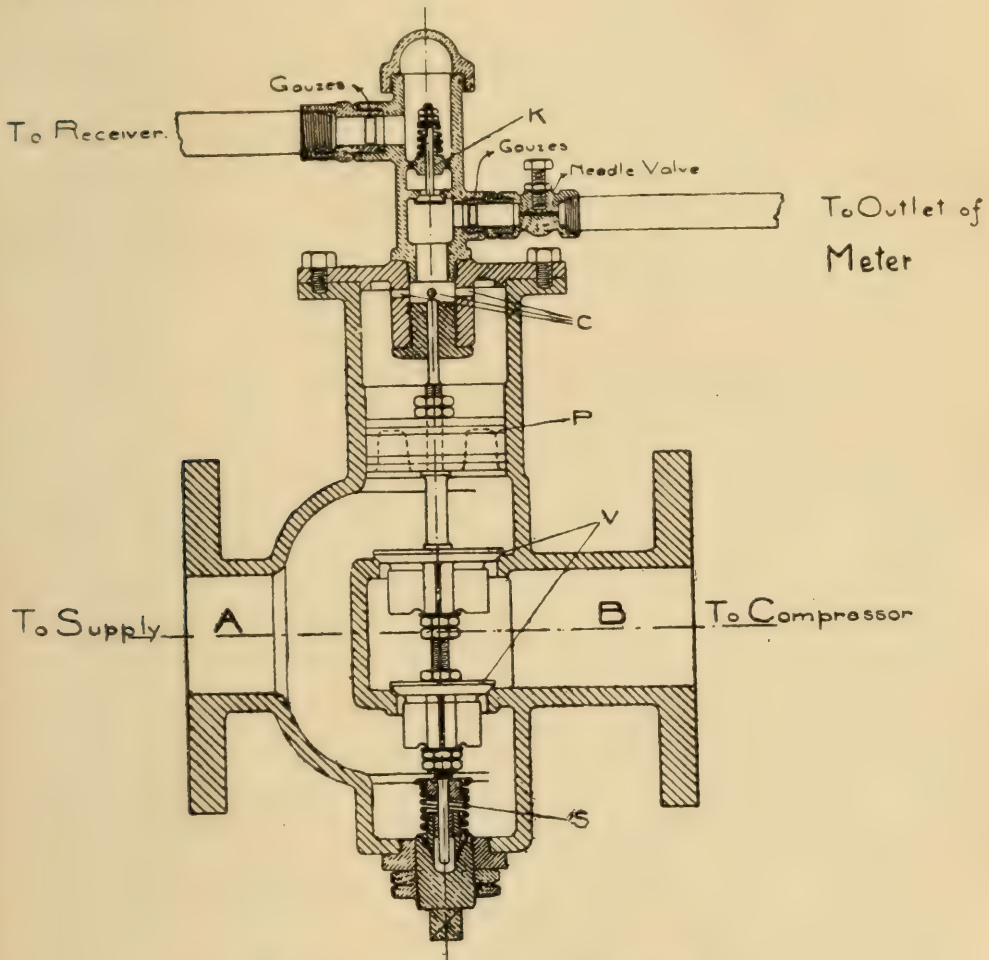
Fig. 8.—Sectional Elevation of Unloader Valve.

The saving of power effected by the employment of an unloader has in some instances amounted to many thousands of horse-power hours per year, whilst at the same time the wear and tear on the compressor itself is reduced to a minimum.

Costs of Compressing Gas.

It is found that for each pound of gas compressed and delivered at a gauge pressure of 12 lb. per square inch, an expenditure of

energy amounting to about 36,500 ft. lb. is required, which, allowing for the inefficiencies of compressing plant, corresponds to approximately 1 B.H.P. hour for each 1000 ft. of gas compressed and delivered at this pressure. In the case of a compressor dealing with 10,000 c. ft. of gas per hour and compressing up to 12 lb. per square inch, the cost of compressing plant would be about £300,* and the cost of compressing, including interest on capital outlay, depreciation, renewals, oil, waste, stores, labour and attendance, and power charges (assuming power to cost 0·75 pence per horse-power hour), would amount to approximately 1·75 pence per 1000 c. ft. of gas compressed and delivered, the total gas dealt with amounting in this case to approximately $22\frac{1}{2}$ millions c. ft. per annum.

Combined High-pressure Gas and Air Systems.

In cases where the high-pressure gas injector burner will not fulfil such conditions as may be required for processes such as the melting of pure nickel, where extremely high temperatures are necessary, or in the case of the melting of swarf or scrap in pots of large capacity with a maximum speed of melting, recent experimental work has shown that with a combination of gas at a working pressure of about 4 lb. per square inch and air at a pressure of about 20-in. water-gauge (as might be obtained from a high-pressure fan), excellent results may be obtained with suitably designed burners. In this case a double injector burner is employed, the mixture being injected into a mixing chamber prior to passing into the burner tube, and with efficient mixing, by employing air and gas at the pressures mentioned, a mixture velocity of about 10,000 ft. per minute can be obtained in the burner tube. I might mention, however, that when working with these high velocities the life of the lining is considerably shortened and the furnace maintenance costs increased.

Fig. 9 represents a burner designed primarily for use with low-pressure gas and air, under a pressure of about 2 lb. per square inch, but which can be modified by the attachment of another injector for use with both gas and air under pressure, as referred to above.

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* Pre-war prices.

Before concluding this paper, the author desires to make mention of another advantage to be gained by employing gas at moderate pressures of about 4 lb. per square inch, instead of at

Fig. 9.—Burner designed for Low-pressure Gas and Air or High-pressure Gas and Air under Pressure.

the ordinary pressure of about 3-in. water-gauge, in connection with heating plant fitted with burners designed for use with air at a pressure of about 2 lb. per square inch and gas at ordinary pressures, owing to the relatively small variation in the quantity of gas consumed which takes place for a given variation in the supply pressure when the supply pressure is high, as compared

with that which takes place when the supply pressure only amounts to about 3-in. water-gauge.

Taking as an example the variations in the quantity of gas consumed, with a given adjustment, which would take place for a pressure variation of, say, $\frac{5}{10}$-in. water-gauge, with working pressures of 3-in. water-gauge and 4 lb. per square inch respectively, these would amount to about 8·5 per cent. in the former case, as compared with about 0·2 per cent. in the latter case.

It is not infrequent that pressure variations of $\frac{5}{10}$-in. water-gauge are met with, especially in establishments in which the loads on the gas supply systems vary considerably from time to time, and as it is not always practicable to govern gas pressures at each point of supply, the application of the combined system of gas and air with each under a positive controllable pressure should be a subject to receive more attention in the future.

In conclusion, the writer begs to acknowledge his indebtedness to the City of Birmingham Gas Committee for their permission to read this paper ; to his assistants for the help they have given in its preparation ; and to the various firms employing high-pressure gas furnaces, who have been good enough to supply the various data, and given permission for its publication.

METAL MELTING.*

By H. M. THORNTON, M.I.Mech.E., and HAROLD HARTLEY, M.Sc.

The Melting of Brass and Copper in a Crucible Furnace with Coal-Gas Fuel.

THE marked success achieved by furnaces employing coal-gas as a fuel, in the heat treatment of metals such as steel, is proving of material assistance in the introduction of gas-fired, metal melting crucible furnaces. Although it would be premature to claim that these latter are fully established, nevertheless, as will be seen from the data to be given later, they offer great possibilities.

It is proposed in this communication to deal only with a furnace of the type intended for melting the metals of higher melting point from brass upwards, as we feel that in this direction coal-gas and water-gas are especially capable of giving the desired results.

General Considerations.

In working with coal-gas the fact must not be overlooked that in terms of B.Th.U. available the fuel is costing from four to five times as much as coke, assuming the gas supply to give 500 B.Th.U. per c. ft. net at a cost of 2s. per 1000 c. ft., and even with water-gas the fuel is considerably more costly per B.Th.U. than the coke which it is intended to replace. Starting with this disadvantage, the furnace manufacturer has either to obtain a markedly greater thermal efficiency out of his appliance or to effect economies in other directions, such as a decrease in the metal losses, greater life of pots, increased daily output per furnace, with a corresponding decrease in establishment charges per cwt. of metal melted, by a saving in labour charges or by a saving in foundry space, all of which tend to the desired increase in over-all efficiency and can be translated ultimately into £ s. d.

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* Presented at Annual General Meeting, London, March 22, 1917.

It is probable that the cast metal prepared with the gaseous fuel would give better results than that obtained by coke melting in those cases where sulphur content is an important factor.

Fuel Consumption.

Just as in the case of solid fuel, this is determined with a given furnace by the specific heat of the solid metal between the temperature of the atmosphere and the melting point, the latent heat of fusion, and the specific heat of the molten metal. The effect of this latter factor may be very important in those cases where a high degree of fluidity is required or desired for any specific purpose.

Temperature of Molten Metal.

When asked to quote fuel consumptions, the furnace manufacturer may feel himself in somewhat of a quandary unless the melter can provide some fairly precise information as to the pouring temperature required, and in the test data given later we have included the temperature of the metal before pouring, just before the crucible was lifted out of the furnace. These temperatures were obtained by means of a Pt/PtRh thermocouple.

In our work with brass and copper the pouring temperature has ranged about 100° to 150° C. above the liquidus. We have found such temperatures generally satisfactory for work of a varied nature carried out in our Pattern Foundry. In this connection it is of interest to recall the work of J. M. Lohr, published in 1913 and abstracted in the Institute Journal, in which the conclusion is drawn, after an examination of the copper-zinc alloys, that the best pouring temperature is between 100° and 200° C. above the liquidus, a higher pouring temperature always producing an oxidized casting. Longmuir's work * also indicates that very hot metal does not give the best results.

Certain workers advise raising the temperature of the metal to a point in excess of that necessary for casting, and then after drawing the crucible from the furnace holding for a sufficient

* *Journal of the Iron and Steel Institute,* 1903 and 1904.

length of time until the mass has cooled to a suitable extent. We notice, however, in a recent article on this subject,* that it is stated, with reference to brass melting, overheating is not advisable, as there is always the danger that it will lead to honey-combing, which is not completely avoided if the metal is cooled before pouring.

Turner and Thorneycroft state † that considerably more heat is required to liberate zinc from alloys rich in copper than to volatilize the liberated zinc, and they give the ratio of the amounts of heat required for the processes as 94 : 6 as a first estimate.

On the basis of these figures, the temperature rise caused by the addition of zinc to molten copper can be calculated. A considerable rise of temperature occurs. The addition of zinc to molten yellow brass does not appear to cause a rise in temperature of the mass, nor does it appear to arrest the cooling of the metal. The following temperature determinations were made on plunging zinc in lump form into 70 lb. of molten yellow brass (70 per cent. copper) :

Time (mins.).	Temperature. °C.
0	1132
1½	1115 (1 lb. of zinc added)
2	1108
3	1088 (1 lb. of zinc added)
4	1062

In an abstract in the Journal of the Institute for 1914 is given a list of various commercial brasses with the temperatures at which they pass completely into the liquid state.‡ From this list the following are taken :

Metal.	Cu.	Zn.	Sn.	Pb.	Melting Point.
Gun metal	88	2	10	...	995
Red brass	85	5	5	5	970
Half yellow } Half red	75	20	2	3	920
Cast yellow brass	66·9	30·8	...	2·3	895
To these we add : Copper	...	...	...	...	1084
Copper, 3·5 per cent. cuprous oxide	...	...	...	...	1065

* *Metal Industry*, Oct. 13, 1916.
† *Journal of the Institute of Metals*, 1914, vol. xii.
‡ Gillett and Norton, *Metal Industry*, 1914, vol. 6, p. 12.

Brass Melting.

Starting from cold a certain amount of energy is required to heat up the bodywork of the furnace, and the additional fuel needed for this purpose acts as a handicap in the endeavour to obtain low average consumptions, the over-all effect of which is decreased by increasing the number of melts carried out successively. For the fourth and subsequent melts it is found generally that the gas consumption per lb. of metal melted remains practically constant. In the last melt of the day a small saving is effected, owing to the fact that there is no excess of brass in the metal preheating chamber, and in consequence the degree of preheating of both the metal and air increases. If time will allow it is possible to increase this saving by a judicious checking of the gas supply and consequent abstraction of heat from the furnace walls, as the combustion chamber will be considerably hotter than the crucible and its contents.

Below are given results of a typical run, limited to six melts to avoid repetition, and added are the average consumptions on the basis of 12, 15, and 20 melts.

Brass Melted.

(General scrap and ingots obtained previously from mixed scrap.   For approximate composition see " Original Metal," p. 219.)   Brass and air preheated.

No. of Melt	1.	2.	3.	4.	5.	6.
Weight of metal charged (in pounds)	68	68	68	68	68	68
Including scrap	8lb. 14oz.	3–15 oz.	2 lb. 9 oz.	6 lb.	7lb. 10oz.	6lb. 11oz.
Amount of metal preheated	12	All	All	All	All	All
Gas.						
C. ft. per lb. metal melted	4·93	2·09	1·78	1·66	1·60	1·40
Cal. val. net.		554·8 B.Th.U.		per c. ft.		
B.Th.U. per lb. metal melted	2644	1121	955	891	858	751
Pouring temperature		990° C. to 1010° C.				
Duration of melt (in minutes)	86	38	34	31	31	30
Weight of skimmings				10 lb.		

Sawdust added to decrease oxidation. No flux used. No zinc added prior to pouring.

Summary.

	Gross Consumption per Lb. Metal Melted.	B.Th.U. per Lb. Metal Melted.
	Cubic Feet.	
Average for 6 melts	2·25	1203
,, ,, 12 ,, ...	1·92	1031
,, ,, 15 ,, ...	1·86	996
,, ,, 20 ,, ...	1·79	962

If it be desired to raise the temperature of the brass 100° C. higher than that in the above test, then it is estimated that the gas used per lb. of metal melted would be increased by 20 per cent. (*Vide* p. 225.)

METAL LOSSES.

The weight of dross is sometimes unduly swelled, owing to the moulder putting his skimmer too deeply into the metal, and this we find more often to happen when no flux has been added to form a protective covering.

To some extent opinion would appear to be divided on the question of the desirability of employing a flux in brass melting, and no doubt the decision taken in many cases is largely determined by the final temperature required. When it is intended to work with very hot metal it may be thought to be advantageous to use a flux, on the ground that it would form a more impervious covering than charcoal and thus lessen the volatilization of zinc.

When a flux is used the weight of metal cast appears to differ less from the weight of metal charged than when only charcoal is used, due apparently to brass becoming intermingled with the charcoal in the latter case. Analyses, to which attention will be called later, of two brasses remelted several times (*a*) with a sawdust covering, (*b*) with common salt as a flux, indicate that the loss of volatile constituents is much the same even when the metal is rendered very hot. In the same series of tests the weights of dross withdrawn from the pot were :

(*a*) From 1 lb. 4 oz. to 1 lb. 8 oz. per melt.

(*b*) 14 oz. in melts 1 to 4, 8 oz. in melt 5. Weight of salt added originally, 4 oz. per melt.

McWilliam and Longmuir * state that " the best quality alloys

* " General Foundry Practice," 2nd edition, p. 328.

are always produced without fluxes, and extensive experiments in this direction are not at all favourable to any type of flux during melting."

In an article dealing with the manufacture of cartridge brass, C. R. Barton * recommends the use of common salt as a flux and phosphor copper as the deoxidizer in crucible melting, and further mentions that this type of furnace is preferred for the work despite the relatively high cost of crucibles, which, he says, have on the average a life of 25 melts (200 to 220 lb. size) in coke-fired furnaces.

For ourselves, we find a certain amount of inconvenience attached to working with a salt covering, owing to the acid fumes produced. This flux appears to attack the crucibles markedly, and if thrown into the furnace at all carelessly may be blown into contact with the outside of the pot and rapidly end its days. Deterioration of the firebrick lining due to the salt would depend apparently on the temperature of the furnace when the salt came into contact with the walls. If the fireclay was hot enough to form a glaze at once no great trouble would be antici- pated ; on the other hand, if the temperature were lower and the NaCl vapour had an opportunity of diffusing into the brickwork and reacting with it later, the result would be unpleasant.†

On the other hand, salt is stated ‡ to be useful in small quantities, admixed with charcoal to prevent absorption of sulphur by molten copper and its alloys, an advantage of little moment with coal-gas fuel ; and to lessen the retention of viscid metal by the dross.

The fluxes used more generally are borax, calcium fluoride, glass, and potassium hydrogen sulphate.

We ourselves incline to the view that the most satisfactory results are obtainable by the use of a charcoal or similar covering together with a small amount of flux.

In an inert atmosphere the rate of loss of zinc from a given brass will depend on the temperature and the speed of flow of the gases over the metal. During melting the process may be accele- rated, owing to the oxidation of the zinc vapour and consequent reduction of the partial pressure of the metallic vapour. The

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* *Journal of the Society of Chemical Industry*, July 15, 1916, p. 740.
    † Cobb, " Effect of Salty Coals on Coke-oven Linings," *Journal of Gas Lighting*, March 1916.
    ‡ *Metal Industry*, Feb. 23, 1917. Abstracted from *Brass World*.

effect of this latter factor is decreased to some extent if the com-
bustion of the gases is not completed in the pot chamber, and
still further if a covering of charcoal is employed.   In the final
heating stage, after the metal is molten and when the greatest loss
occurs, a crucible lid previously heated in the metal preheating
chamber can be used to cover the pot and decrease the loss.

Assuming that it requires in the respective furnaces 3·0 c. ft.
of coal-gas, or 0·5 lb. of coke per lb. of metal melted ; then if the
gas is burnt completely to CO_2 in the pot chamber, the volume of
products (calculated at 0° C. and 760 mm.) will be about 14 c. ft.,
whereas with the coke if it burns to CO_2 there would be about
77 c. ft. of products, and if only CO were formed, about 45
c. ft.   From three to five times the volumes of products flowing
through the gas-fired furnace pass through the coke furnace.

In brass melting in coke crucible furnaces the zinc loss is stated
often to be large, in which case it must be an important factor,
both from the economic point of view, which is of especial moment
at present, and, unless corrected for prior to pouring, with regard
to its effect on the mechanical properties of the resulting alloy.

Statements have been published that in the process of melting
brass, as generally carried out, about 20 to 25 per cent. of the weight
of zinc originally added is lost ; compensation is made for this by
plunging a piece of spelter into the molten bath and involves a still
further loss of metal.

McWilliam and Longmuir cite the case of a manganese bronze
which they remelted in a crucible furnace (coke ?) to determine
the zinc loss.   They give the following analyses * :

	Original Metal.	Remelted and Sand Cast.
Copper	59·00	68·88
Tin	0·58	0·86
Zinc	37·92	28·13
Iron	1·40	1·45
Manganese	0·42	0·23
Aluminium	0·48	0·20

Unfortunately no details are given of the period of heating, of
the temperature attained, or the state of division of the metal
charged.   It will be noticed that the zinc loss is about 25 per cent.,
and the manganese loss about 50 per cent.   Further, these authors
state that they estimate the original metal would have a maximum

* *Loc. cit.*, p. 360.

stress of 25 to 28 tons per square inch, whereas the remelted metal would not sustain more than 15 tons per square inch.

They also give a series of results showing the losses in making different brasses " in typical crucible furnaces " : these vary from 28·6 per cent. in the case of red brass when a temperature of 1308° C. was attained to 19 per cent. when making Muntz metal, the maximum temperature in this latter case being 1038° C.

We have investigated this point in connection with gas-fired furnaces, and although anticipating some saving, the great difference between our results and those of the authors just quoted cannot be put down solely to the credit of the gas furnace.

The high loss of zinc in the remelting of the above manganese brass is conceivably due, in part at least, to the presence of the β phase in that particular sample, as Thorneycroft and Turner * have shown that the β alloys part with zinc much more readily than the a solutions with which we were concerned. According to Thorpe's Dictionary,† 5 per cent. represents the maximum loss of zinc usually experienced in the making of brass when the volatile constituent is added to the copper in large pieces.

H. W. Gillett ‡ states that in current practice of brass melting 5 per cent. of the original metal is lost ; later he says that reports of metal losses vary from 1 per cent. to 22 per cent.

Recently, in making up a red brass containing a little tin in four 50-lb. lots, we found the average zinc loss not to exceed 3·0 per cent.

In connection with the determination of zinc loss on remelting yellow brass, the following tests were made.

Two 70-lb. lots of works scrap brass A and B were melted and cast into chills, sample ingots being retained for analyses. Batch A was then remelted with a covering of sawdust only, cast into ingots, a test ingot withdrawn, and the remainder returned to the crucible, remelted, and a further sample taken. This treatment was repeated, five remelts in all being made. In the last melt, after the pourers had approved the metal to be sufficiently hot for casting purposes, the crucible was left in the furnace for another half-hour, the temperature of the metal being raised steadily during the whole of this period.

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* *Loc. cit.*   † Vol. v. p. 816, " Cast Brass."
‡ *Bulletin of the U.S. Bureau of Mines*, 1914.

The second batch of metal B was treated in a similar manner, except that in this case a covering of common salt was employed, and no provision of charcoal made for the prevention of oxidation. In neither case was a crucible lid used. The analyses of the various ingots withdrawn during the series are given below. These test ingots weighed about 3 lb. each.

Variation in Composition on Remelting Brass repeatedly.

SERIES A.

	Original Metal.	Remelts.				
		1.	2.	3.	4.	5.
Copper (by difference) . .	70·57	71·44	71·76	71·67	71·54	73·27
Zinc	24·77	24·65	24·45	24·15	23·63	22·14
Tin	1·34	1·24	1·19	1·15	1·38	1·29
Lead	2·99	2·22	2·04	2·60	2·93	2·75
Iron	0·33	0·45	0·56	0·43	0·52	0·55
Duration of heating period (in minutes) . .	...	122	44	40	30	53
Pouring temperature . .		990° C.	o 1015° C.			1180° C.
Weight of skimmings . .	...	21 oz.	22 oz.	24 oz.	24 oz.	24 oz.

SERIES B.

	Original Metal.	Remelts.				
		1.	2.	3.	4.	5.
Copper (by difference) . .	70·01	70·24	70·29	70·50	71·08	72·45
Zinc	25·29	24·97	24·72	24·46	23·96	22·68
Tin	1·30	1·21	1·26	1·30	1·37	1·29
Lead	2·78	3·12	3·19	3·29	3·27	3·12
Iron	0·62	0·46	0·54	0·45	0·32	0·46
Duration of heating period (in minutes) . .	...	95	40	34	29	58
Pouring temperature . .		990° C. to 1015°		C.		1180° C.
Weight of skimmings . .	...	14 oz.	14 oz.	15 oz.	14 oz.	8 oz.

Zinc Loss during Remelting ; per Cent. Zinc present Originally.

Melts No.	0 to 1	to 4	to 5
Series A	0·48 per cent.*	4·26 per cent.	6·19 per cent.
Series B	1·34 ,, ,,	4·04 ,, ,,	5·63 ,, ,,

* Total for three remelts.

The loss occasioned by heating to 1180° C. was about $4\frac{1}{4}$ times the average loss in each of the preceding melts.

Red Brass.

We had occasion recently to carry out for a client a series of melts with a red brass containing about 2 per cent. tin in 60-lb. lots. Only three successive melts were made on each occasion. The average results are appended, together with the gas consumptions for melting yellow brass under the same conditions.

No. of Melt	1.	2.	3.
Weight of metal charged (in pounds). . .	60	60	60
Amount preheated	12	All	All
Gas.			
Consumption c. ft. per lb. of metal melted .	6·10	2·43	2·14
Cal val. net.		548 B.Th.U.per c. ft.	
B.Th.U. per lb. of metal melted . .	3256	1297	1142
Duration of heating (in minutes) . . .	98	38	34
Pouring temperature		1090° C.	

Gas consumption (average for three melts), c. ft. per lb. melted :
    Red brass (pouring temperature, 1090° C.) . . . . . 3·56
    Yellow brass (pouring temperature, 990° C.) . . . . . 2·95

Analyses were made of the red brass prior to the first test melt and after the second melt ; they are appended :

	Original Metal.	After 2nd Melt.
Tin	2·52	2·69
Zinc	9·85	9·50
Lead	0·19	0·35
Iron	0·05	0·25
Copper (by difference)	87·39	87·21

Zinc loss during two melts, per cent. original content = 3·56.
The preferential loss of zinc is thus seen to be small.

Gun Metal.

C. P. Karr * has given the results of a series of tests of gun metal (88·10·2), carried out in connection with the Bureau of Standards, in which different manufacturers remelted a quantity of metal sent to them. The zinc loss was found to be inappreciable. Pouring temperature, 1100°–1200° C.

Copper.

From the results of the melting tests with this metal given below, it will be noticed how important is the ability to load up

* *American Institute of Metals,* Sept. 1916.

the pot as much as possible. Materially better results were obtained when the charge was mixed scrap and ingots than when only sheet scrap was handled.

Melting of Sheet Copper Scrap.

No. of Melt					1.	2.	3.	4.
Weight melted (in pounds).			.	.	60	60	60	60
Weight preheated (in pounds)		.	.	.	28	All	All	All
Gas.								
C. ft. per lb.	.	.	.	.	8·15	4·98	3·52	3·25
Net cal. val	.	.	.	.	.	518·4 B.Th.U.	per c. ft.	
B.Th.U. per lb.		.	.	.	4197	2564	1812	1673
Duration of heating (in minutes).			.	.	141	88	60	57
Pouring temperature .		.	.	.		1220° C.		

Average for Four Melts.
C. ft. of gas per lb. metal melted = 4·98
B.Th.U. per lb. metal melted = 2561

The metal was cast in ingot chills. Subsequently these ingots were melted, with the addition of a little more sheet scrap. The melting results are appended :

Copper Melting — Ingot + Scrap.

No. of Melt	1.	2.	3.	4.	5.	6.	7.
Total charge (in pounds)	68	68	68	68	68	68	68
Including scrap . .	1 lb. 9 oz.	1 lb.10 oz.	3 lb. 1 oz.	1 lb. 10 oz.	6 lb.15 oz.	10 oz.	5 lb.
Amount pre-heated .	8 lb.	All	All	All	All	All	All
Gas.							
C. ft. per lb.	8·23	3·12	3·10	2·81	2·45	2·47	2·23
Cal. val. net			530·3	B.Th.U.	per c. ft.		
B.Th.U. per lb. . .	4295	1629	1618	1467	1278	1289	1163
Duration (mins.) .	151	54	56	48	42	43	42
Pouring temperature				1210° C.			

Summary.

	C. Ft. per Lb. Melted.	B.Th.U. per Lb. Melted.
Average for 5 melts (Nos. 1, 2, 3, 4 & 7) .	3·90	2034
,, ,, 6 ,, (,, 1, 2, 3, 4, 5 & 7)	3·66	1908
,, ,, 7 ,, ...	3·49	1820

The markedly improved results obtained in this second series of melts indicate that the massive form of the metal is more suitable for melting in this type of furnace. Ability to pack the pot well is important if the most economical melting is desired.

To emphasize this point we draw attention to the following table. The melts were made on three different days, starting with the furnace cold in each case, the charges being :

A. Copper sheet scrap.

B. Copper ingots and sheet scrap.

C. Copper allowed to solidify in the crucible after the previous day's melt.

	A.	B.	C.
Weight melted (in pounds)	60	68	68
Weight preheated (in pounds)	28	24½	nil
C. ft. gas per lb.	8·15	7·94	7·59

THERMAL EFFICIENCY.

An approximate idea of the efficiency of the furnace will be of interest, and also it may enable us to compute within reasonable limits the extra consumption allowance which must be made when high pouring temperatures are required for any particular purpose ; moreover, the result indicates the degree of success that has been attained in the construction of the class of furnace which we are discussing. Using the data given above for copper, the following results are obtained :

Fifth Melt.

Gas consumption per lb. of metal melted = 2·45 c. ft.

Temperature, 36° F.; pressure, $\frac{11}{16}''$ water.
Barometer, 761·1 mm. ·

Thus gas consumption per kilo molten metal corrected to 0/760

= 5·39   c. ft.

Net cal. val. of gas = 133·6 K.C.U. per c. ft.

Thus heat supplied to furnace per kilo copper melted

= 709 K.C.U.

Assume.—Specific heat of copper 14° C. to 1084° C.   = 0·11 K.C.U. per kilo per ° C.
Specific heat of copper 1084° C. to 1210° C. = 0·16   ,,   ,,   ,,
Latent heat of fusion of copper   = 43   ,,   ,,   ,,
Thus total heat supplied to the copper   = 181 K.C.U.

Therefore efficiency = $\frac{181}{709} \times 100 = 25 \cdot 5$ per cent.

The over-all efficiency for the six melts quoted = $\frac{2 \cdot 45}{3 \cdot 66} \times 25 \cdot 5 = 17 \cdot 1$ per cent.

This latter figure will rise gradually as the number of melts is increased.

From the results given for brass and combined with those obtained with copper, it is possible to arrive at an estimate of the additional gas consumption necessary to heat the brass to a considerably higher temperature.

If it be assumed that the specific heat of brass is the same as that of copper (at ordinary temperatures this is very nearly so), and that the heat allowance to be made for the liquefaction of the brass is 38 K.C.U. per kgm. ; then the steady state efficiency during the fifth brass melt (p. 216) (metal poured at 990° C.) = 30 per cent.

Over-all efficiency for six brass melts (990° C.) = 21·3 per cent.   Thus we can assume for six consecutive melts :

Temperature Attained. ° C.	Over-all Efficiency. Per Cent.
990	21·3
1090	19·4
1190	17·2

From this we see that to get the brass to 1090° C. would require about 1456 B.Th.U. per lb. (364 K.C.U.), or approximately 253 B.Th.U. more than was expended in the test given on p. 216 *i.e.* an additional 0·45 c. ft. of gas per lb. of metal on the six melt basis.   With an increased number of melts the actual gas used on the basis of the average for the day's work decreases, but still remains about 20 per cent. more than that required for 990° C.

We have not been able to secure satisfactory data concerning coke consumptions for the melting of copper, but are informed that 0·5 lb. of coke per lb. of metal represents an average figure for brass melting.

If the net cal. val. of the coke = 12,000 B.Th.U. per lb., then 6000 B.Th.U. are employed per lb. of brass melted.

With 560 B.Th.U. gas the six melts were done at an average consumption of 2·25 c. ft. per lb. gross, equal to 1200 B.Th.U. per lb. of metal melted, from which it would appear that, roughly, the thermal efficiency of the gas furnace is about five times that of many coke furnaces, the latter converting approximately 4 per cent. of the available energy into useful work.

Gillett * states that in the melting of all non-ferrous alloys

* *Loc. cit.*

90–95 per cent. of the heat units in the fuel do no useful work ; he also mentions reports of fuel efficiencies varying from $1\frac{1}{2}$ to 16 per cent. received during his inquiry.

Advantages of Preheating.

The results which we have given were obtained in a gas-fired furnace, with an arrangement for preheating the metal prior to charging, and for preheating the air supply before it is admitted to the blast burner.   A simple calculation shows that preheating can effect a considerable saving of fuel, and that if the brass and air are preheated to the same temperature prior to admission to the furnace proper, a considerably greater regeneration results from the brass than from the air.   Thus assuming the metal was to be poured at 1000° C., if the brass be preheated to 600° C. roughly a 40 per cent. saving can be effected, whereas if the air were preheated to the same extent—and this offers great difficulties— the saving would be 20 per cent., neglecting the effect on the temperature attained in the combustion zone.

In the case of copper, the saving to be anticipated from preheating the metal to 800° C., with a pouring temperature of 1250° C., is 47 per cent.

In actual practice we have obtained with brass the following results, pouring at about 1000° C. :

No. of melts made consecutively	4	6
Gas Consumption per Lb. of Metal Melted.		
No preheating (a)	3·10	2·91
Brass preheated (b)	2·72	2·48
Brass and air preheated (c)	2·42	2·17

The actual consumptions for the fourth melts being :

(a) 2·52 c. ft. per lb.
(b) 1·99 ,, ,,
(c) 1·66 ,, ,,

Thus it is evident that for brass melting the most suitable type of furnace to be employed will depend upon the number of melts required daily, as when only a few melts are required the additional capital cost involved in the introduction of the pre- heating device may not be compensated for adequately by the gas saved.   It will hardly be necessary to mention that if the furnace is suitably constructed the metal and air are both pre-

heated to a considerably higher temperature in melting copper or cupro-nickel than when melting brass.

LIFE OF POTS.

A well-made graphite crucible is capable of withstanding very sudden temperature changes to an almost surprising extent. W. F. Downs * stated that he heated a small crucible to 1400° C. and plunged it into cold water, and repeated this treatment twelve times before any change could be detected in the note produced on tapping it with an iron bar ; after repeating this treatment twenty times the note was practically gone. He makes the further statement that in actual commercial use for melting purposes a crucible has been known to stand from 80 to 100 charges in melting copper or a similar metal. This view is largely endorsed by F. Cirkel in his monograph on graphite. The latter says : " They stand in the manufacture of brass from 35 to 45 melts, when clay crucibles only stand from 4 to 6 melts. The very best crucibles made of the very best quality crystalline graphite can stand from 50 to 60 and even 70 heats of brass, a crucible made of amorphous or dense graphite will only stand from 6 to 8 heats. After every heat attention must be given to the removal of slag."

These statements refer to coke-fired furnaces, and although many melters only claim about 30 melts per pot it is an indication at least that, given favourable conditions, much better results are obtainable. The care adopted in the use of a crucible, and especially during the initial melt, is of outstanding importance. Barton states † that in making cartridge brass the average life of a pot (200 lb. size) is 25 heats, but is much shortened by ill-fitting tongs, excess of fluxes, " soaking " in the furnace, excessive furnace temperatures, wet or sulphurous fuel, and carelessness in stirring and handling.

Gillett ‡ emphasizes the importance of using properly fitting tongs, and appears to prefer the " Grab " to the " Pinch " type. He draws attention to the danger of wedging the crucible full of cold ingots or scrap, which on heating expand more than the pot and may cause splitting. In coke furnaces he says crucibles

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* *Iron Age*, May 24, 1900, p. 5.   † *Loc. cit.*   ‡ *Loc. cit.*

may be badly injured mechanically by carelessness in poking the fire or in knocking off slag and clinkers. Excessive temperature changes of the pot should be avoided ; if the best results are to be obtained they should not be allowed to cool too much between melts.

It is often stated to be noteworthy that the best results with regard to pot life are obtained in the brass-rolling trade, and this is attributed to the fact that those users have available and employ a good means of drying their pots prior to use ; the pots being stored on top of the heat treatment furnaces, where they are kept dry. Probably all users take care to dry their crucibles, but it is doubtful whether the same attention is paid to the annealing—gentle heating up to a red heat before charging for the first melt. A little trouble taken at this stage will be well repaid later. Even though the preparation of crucibles may have been sufficient to avoid a " bumped " pot, the danger of the formation of small hair cracks in the pot has to be avoided if the best results are to be obtained. After the first melt has been executed satisfactorily, the crucible would appear to be capable of withstanding drastic heat treatment. It is not in our opinion, however, desirable to take liberties at any time, and we would advise always gentle heat treatment during the first melt of the day, as although the pot may appear to be unaffected by heating it up very rapidly, there is always a danger of forming hair cracks.

In a gas-fired furnace the abrasive action of the solid fuel is eliminated, the direction of flow of the gas stream is under better control, the sulphur content of the fuel is very small (about 30 grains per 100 c. ft.), there is no fire to poke, and clinkers have not to be removed from the outside of the pot, so that it is not surprising that long pot lives can be obtained, especially in the absence of fluxes or with a flux which does not attack the crucible walls viciously. In a gas-fired furnace doing 5 or 6 melts a day no difficulty should be found in obtaining 45 to 50 melts out of a 70-lb. pot, thus comparing very favourably with the coke-fired furnaces. When a furnace is run full time doing 15 to 20 melts per day, and with a gas-fired furnace this is obtainable, a considerable increase in the number of melts per pot results. If the use of a flux does not determine the length of life of a pot, we should expect a 50 per cent. increase in the pot

life when a gas-fired furnace is substituted for one coke-fired—provided, of course, that the melter shows a reasonable amount of care in handling and loading the crucible.

Increased Output.

On the basis of the figures given for brass melting on p. 216, it follows that the average time for the actual melting operation is, for 12 melts of 68 lb. each, 39 minutes, and for 15 melts 37 minutes, making no allowance for the time required to pour. Under similar conditions 55 minutes would probably represent an average for many coke-fired furnaces. With the gas-fired furnace cited above, the average time for melting can be decreased by 3 to 5 minutes by working at a higher consumption without a decrease in the thermal efficiency of the appliance. To claim a saving of time for melting of 25 per cent. with a gas-fired furnace, against ordinary practice with a solid fuel furnace, in the melting of brass would not be excessive.

In conclusion, we wish to state that the results for gas consumptions which we have quoted have all been obtained in the works of the Richmond Gas Stove and Meter Co. by members of their staff, and are not to be regarded as representing " works practice," as ordinarily understood, by which the furnace is debited with the mistakes of the melter. On the other hand, the work has been carried out under such conditions that it would not be unreasonable to expect others in charge of the furnaces to obtain results of the same order. Once the furnace is set going the only duty devolving on the melter is to see that he keeps as much metal in the pot as possible and ensures that there shall be an ample, although not excessive, supply of metal in the pre-heating chamber ; the charges there should be arranged, of course, so that the metal just before it is transferred to the crucible is in the hottest portion of the chamber. Above all, avoid the waste of time ; if the gas consumption is about 3 c. ft. per hour per lb. of brass in the charge to be melted, or even more, it will be obvious that ten minutes wasted means that the average consumption for that particular melt is up by $0\cdot5$ c. ft. per lb., not to mention the possibility of an increased zinc loss, especially in the later stages of the process.

For obvious reasons more constant supervision is desirable in brass melting than in the longer processes of melting copper or cupro-nickel.

Probably the manufacturer will be served well if he arranges a bonus for low consumption on the basis of the output of castings, as in that way he provides a certain amount of protection against cold metal being supplied.

The authors wish to acknowledge the facilities given by the Richmond Co., Warrington, and the assistance of their Research Department in the compilation of many of the particulars given in this paper.

APPENDIX.

DESCRIPTION OF FURNACE.

The metal melting referred to in this communication has all been carried out in a Richmond 70-lb. crucible furnace of the preheating type. The gas and air mixture is admitted through a suitable blast burner into the lower portion of the combustion chamber, and is burnt in the annulus between the crucible and the furnace wall. The gases after travelling around the pot are directed through the metal preheating chamber, and then pass on to the air pipes and finally to the flue. This arrangement enables a high degree of preheat of the metal to be obtained.

The top of the metal chamber is on a level with the top of the pot chamber and is closed by a pair of lids. With this construction the operator has not to lift his metal above the foundry floor level, and the transference of preheated material to the crucible is done with ease.

The lower portion of the wall of the combustion chamber is constructed of suitably shaped blocks of a specially refractory nature to enable greater resistance to be offered to the combined action of high temperatures and spilt metal. The bottom of the chamber can be removed simply for the recovery of spilt metal.

NOTE.

COKE-FIRED FURNACES.*

By H. L. REASON (Birmingham).

Coke-fired furnaces are still the most generally employed for melting brass and other copper alloys.

The ordinary type of pit coke-fired crucible furnace is shown in Fig. 1, which is self-explanatory. The chief preliminary question is as to whether square or round furnaces were to be preferred. The results of a number of tests have proved that the square furnace is the more efficient, as the coke consumption is less than with the round
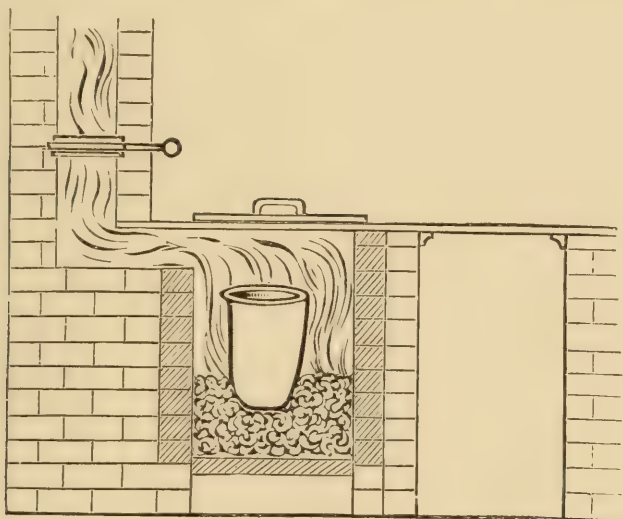
Fig. 1.

furnace, and the square furnace is also much easier to rebuild and keep in repair. In the case of a 100-lb. round crucible furnace it requires 3-in. coke space between crucible and lining, whereas the square furnace only requires $1\frac{1}{2}$ in. at the side. The corners give ample coke space and sufficient room for the lifting-out tongs; the difference in the cubic capacity is 653 c. in. The increased cubic capacity of the round furnace is a cause of greater coke consumption.

If the furnaces are not kept in a good state of repair and the sides are allowed to burn away, the increased coke space will make the furnace

* Presented at Annual General Meeting, London, March 22, 1917.

much hotter at the worn part, and this sets up a cutting action on the crucible ; crucibles are sometimes ruined after four or five heats in this manner. The maximum temperature of natural-draught furnaces for melting copper alloys is about 1600° C., but the average is nearer to 1250° C. For melting nickel-brass or other nickel alloys, it is necessary to have the maximum temperature.

The height of chimney-stacks should not be less than 25 ft., and the chimney must not be lower than any of the surrounding chimneys ; the flues must be vertical for 12 ft. before nesting in. The dimensions

BRASS MELTING FURNACE
PIT TYPE   FRONT VIEW
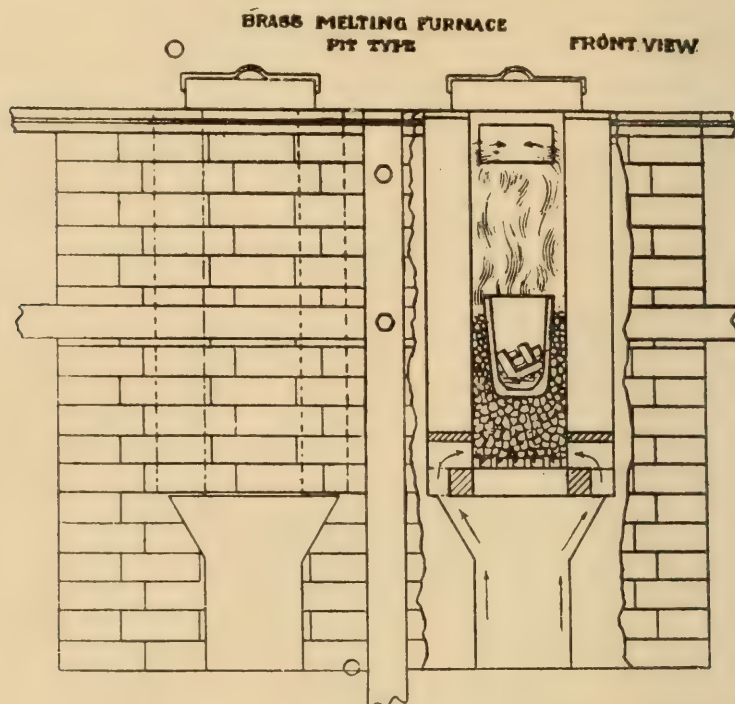
FIG. 2.

of the flues should be 9 in. × 9 in. for furnaces taking crucibles up to a size of 160 lb., or 14 in. × 10 in. for 600-lb. crucibles.

In this form of furnace the fire-bars are removed from the inside. This makes the daily cleaning out, and the removing of metal and clinkers from fire-bars, a tedious operation ; it also damages the lining of the furnace, while if the coke contain a large quantity of ash the furnaceman will often be found in the pit cleaning fire-bars.

Two furnaces of the author's design are shown in Figs. 2 and 3. In these the trouble in removing clinker and fire-bars has been obviated by carrying the lining of the furnace on a cast plate.

The fire-bars are carried on bearers below, leaving out 1½ in. air space between the top of fire-bars and the underside of plate carrying the lining. The fire-bars can be pulled out from the front of the furnace, so that the work of cleaning out the furnaces when starting up in the

mornings is only the work of a few minutes. Air space is arranged round the bottom bearer, and in the event of the fire-bars being choked, sufficient air can be admitted through the sides and over the top of the fire-bars to the work furnace.

BRASS MELTING FURNACE
PIT TYPE

SIDE VIEW
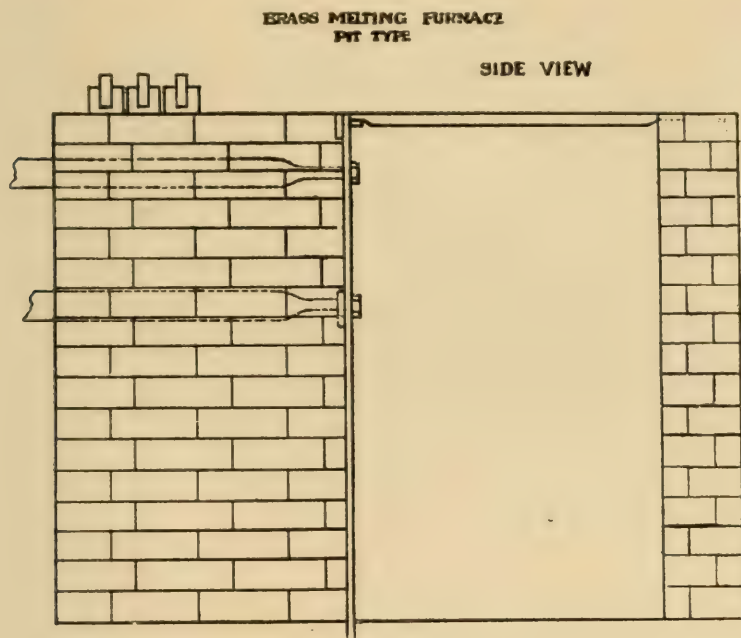
Fig. 3.

The end view of the furnace with tie rods and buck staves is shown in Fig. 3.   There should be 5 ft. 9 in. to 6 ft. clear under gratings, so as to give comfortable room for the workman to walk from end to end for cleaning purposes.

TABLE I.—*Internal Dimensions for Coke-fired Lift-out Crucible Furnaces.*

Crucible.			Square Furnaces. Brass internal dimensions.		
Capacity.	Diam.	Height.	Width.	Depth.	Coke Space at Sides.
Lb.	In.	In.	In.	In.	In.
50	7	$11\frac{1}{2}$	10	27	$1\frac{1}{2}$
60	8	$11\frac{1}{2}$	11	$28\frac{1}{2}$	$1\frac{1}{2}$
70	$8\frac{1}{4}$	$12\frac{1}{2}$	$11\frac{1}{4}$	$29\frac{1}{2}$	$1\frac{1}{2}$
80	$8\frac{1}{2}$	$13\frac{1}{4}$	$11\frac{1}{2}$	30	$1\frac{1}{2}$
100	$9\frac{1}{8}$	$14\frac{1}{4}$	$12\frac{1}{8}$	31	$1\frac{1}{2}$
120	$9\frac{1}{2}$	$15\frac{1}{2}$	$12\frac{1}{2}$	$32\frac{1}{4}$	$1\frac{1}{2}$
150	$10\frac{3}{8}$	$16\frac{3}{4}$	$13\frac{1}{2}$	34	$1\frac{1}{2}$
200	$11\frac{1}{4}$	18	$14\frac{3}{4}$	36	$1\frac{3}{4}$
250	$11\frac{1}{2}$	$19\frac{3}{4}$	15	38	$1\frac{3}{4}$
300	$12\frac{1}{2}$	21	16	40	$1\frac{3}{4}$

The average loss in melting with coke-fired furnaces for brass castings is about 5 per cent., the loss being chiefly in the zinc content.
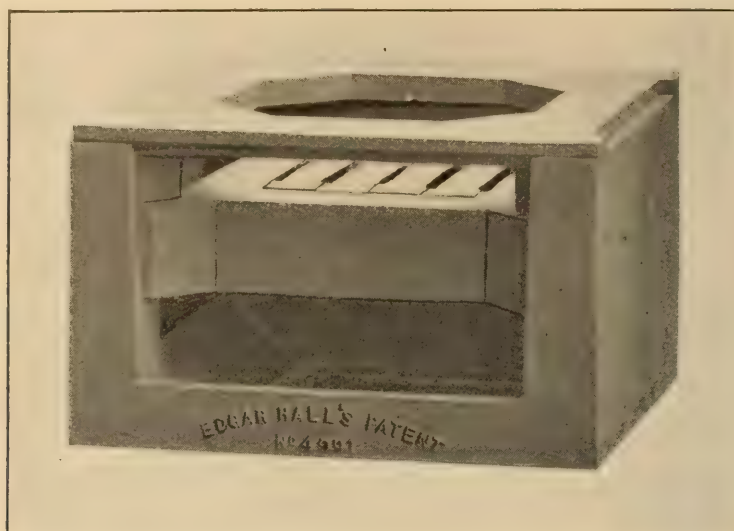
FIG. 4.

In Table I. (p. 233) are given the correct internal dimensions for coke-fired lift-out crucible furnaces.

When it is decided to instal brick-built furnaces, the author would

FIG. 5.

advise the use of a cast-iron furnace bottom similar to the Hall type shown in Fig. 4, which obviates the troubles with regard to want of sufficient air. The box is placed upon the two brick pillars which form the ash hole and the furnace is built up on the top plates. The slanting

slides inside allow the ashes to fall away readily, and there is ample air space round the fire-bar frame to work the furnace.

·WIGLEY'S IMPROVED ADAPTABLE FURNACE BOTTOM·
APPLIED TO NEW OR EXISTING CRUCIBLE FURNACES
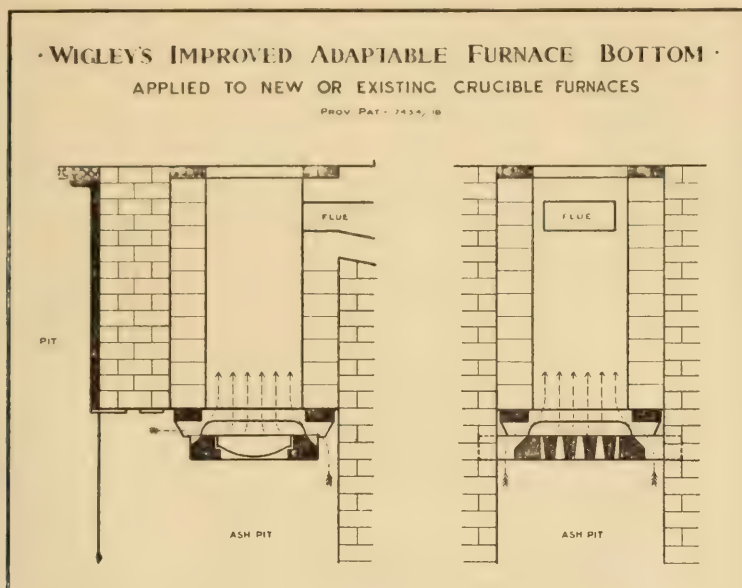
Fig. 6.

Another form of furnace bottom which can be recommended is that introduced by Wigley, which is shown in Figs. 5 and 6.

A number of these furnaces are in use, and they are found to be a great improvement over the old pattern bottom.
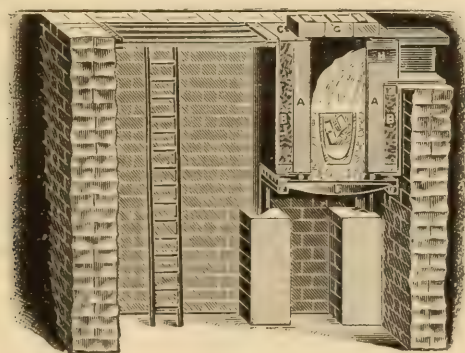
Fig. 7.

Another form of furnace in fairly general use is that by Carr of Smethwick. (Fig. 7.)

The principle of the furnace was embodied in the brick-built furnace that the author has already described.

Coke-fired furnaces of the tilting type have been introduced by the Morgan Crucible Co., and these are meeting with approval in various works in the Midlands.

TABLE II.—*Approximate Cost of Fuel for Different Types of Furnaces.*

No.	Type of Furnace.	Size.	Class of Fuel.	Quantity of Fuel per Cwt. of Metal Melted.	Remarks.
1	Reverberatory	¾ cwt. to 2 cwt., 2 ton to 20 ton	Coal	84 lb.	Smaller furnaces which can be worked continually, the coal consumed being reduced about one-third
2	Pit lift-out crucible	300 lb.	Hard coke	28 lb.	Time melting 45 to 60 minutes
3	Pit lift-out crucible	300 lb.	Gas coke	36 lb. to 42 lb.	In small furnaces 60 lb. and under the difference between hard and gas coke is not so marked
4	Coke tilting furnace	400 lb.	Hard coke	24 lb.	Blast pressure 1½ to 2-in. water-gauge
5	Oil tilting crucible furnace	400 lb.	Crude creosote or tar oil	1¼ gall.	Blast pressure from ⅓ lb. to 25 lb. according to type of furnace and burner
6	Oil tilting furnace without crucible	400 lb.	Crude creosote or tar oil	2½ gall.	
7	High-pressure gas crucible furnace	60 lb.	High-pressure gas	250 c. ft. per hour	Pressure 12 lb. per sq. in. High pressure gas 1s. 3d. per 1000 c. ft. Time melting 60 lb. 50 minutes

In conclusion, the author would direct attention to the above table, giving the approximate cost of fuel for various types of furnaces.

Total cost of compressing the ordinary town gas to 12 lb. per sq. in., including interest and depreciation on plant, labour, and power, costs should not amount to more than 2d. per thousand c. ft. of gas compressed and delivered.

NOTE

ON AN ELECTRIC RESISTANCE FURNACE FOR MELTING IN CRUCIBLES.*

By H. C. GREENWOOD, D.Sc.

AND

R. S. HUTTON, D.Sc. (SHEFFIELD).

SOME few years ago the authors carried out a series of experiments, with the object of improving the quality of a range of nickel-silver alloys currently produced at their works for subsequent rolling into sheet metal.

In the electro-plate trade up to two-thirds of the sheet metal is returned to the melting-pot as scrap, and any fresh nickel required in the melting charge is previously alloyed with copper.

Observation showed that the properties of these alloys were greatly influenced by impurities, and that the conditions of melting played an important part in the production of material with the best working qualities. Bearing in mind the necessary utilization of scrap, it is obvious that any contamination due to the fuel, *e.g.* sulphur, would tend to be cumulative.

It was found that in these respects gas offered advantages over coke, and as other papers are to be presented at this meeting of the Institute bearing on this subject, the following brief remarks may be permitted to summarize the authors' experience of gas melting, so far as nickel silver is concerned.

The advantages of gas over coke were (1) the greater ease of regulating the heating and maintaining a slightly reducing atmosphere ; (2) lower sulphur content ; (3) greater ductility of the alloy, demonstrating itself both by the ordinary mechanical tests as, *e.g.*, higher elongation and greater endurance under torsion, as also in the facility of the production of difficult " spinnings," a matter of great practical importance.

The disadvantages of gas compared with coke, some of which it is hoped are overcome by improvements in the furnaces to be described by other authors, were—(1) Noise ; fumes and hot gas when furnace uncovered for charging, &c. ; (2) decreased life of plumbago crucible ; (3) greater zinc losses, owing to rapid currents of gas ; (4) slower

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* Presented at Annual General Meeting, London, March, 22, 1917.

melting, a point of vital importance for ordinary commercial work.

The fuel costs of working (at that time Sheffield gas of 560 B.T.U. gross per c. ft. was available at 1s. per 1000 c. ft., and metallurgical coke at 27s. per ton) were sufficiently near for practical purposes.

With this experience, and the desire to be able to melt the alloys under more perfect conditions, the authors decided to make experiments with an electrically heated furnace, large enough to take the usual 100-lb. crucible.

An electric furnace of the resistance type was expected to have advantages over a gas furnace as follows :

1. Owing to its quiescent state the atmosphere of the furnace would be completely reducing (since carbon could be introduced into the pot or into the furnace chamber), while loss of spelter would be greatly diminished.

2. Much less sulphur contamination.

3. Greatly enhanced life of the crucibles.

4. Improved quality of the metal.

As regards the choice of the type of furnace to be employed, the authors were influenced by the consideration that it is often necessary to make different grades of nickel-silver in rapid succession ; a furnace of large capacity or one which requires metal to be left in it, as the induction furnace, would therefore be unsuitable. Further, in order to avoid the high current required for a cylindrical resistor, a resistance consisting of carbon rods connected in series seemed the most suitable for experimental purposes. Accordingly the furnace now to be described was constructed. The general form of the furnace can be seen from Fig. 1. Sixteen carbon rods of 1 in. diameter and 19 in. length were arranged in a 13-in. circle, and connected by means of graphite blocks alternately at top and bottom to form two parallel sets, each of eight rods in series. Current was supplied to the two sides of the circle by means of graphite rods ground into holes in the blocks A and B (the carbon rods made electrical connection in the same manner).

The graphite rods were soldered into water-cooled terminal blocks, on to which the supply cables were bolted. To protect the carbon rods from oxidation a mixture of carborundum fire-sand and sodium silicate solution was pasted round them. Owing to an insufficient supply of carborundum fire-sand, the heat insulation of the furnace consisted entirely of kieselguhr. This material is not very refractory, and was rather badly shrunk near to the resistors, which probably somewhat lowered the efficiency of the furnace. A better method of heat insulation would be that shown in Fig. 2, the inner layer (A) consisting of carborundum fire-sand or ordinary sand, and the outer one of kieselguhr (B). The carbon rods here are shown encircled almost completely by suitably shaped carborundum bricks, only a narrow slit remaining to be filled up with the paste, which on large

surfaces tends to drop out. One has here the advantage of the veɪy high thermal conductivity of carborundum bricks serving to equalize
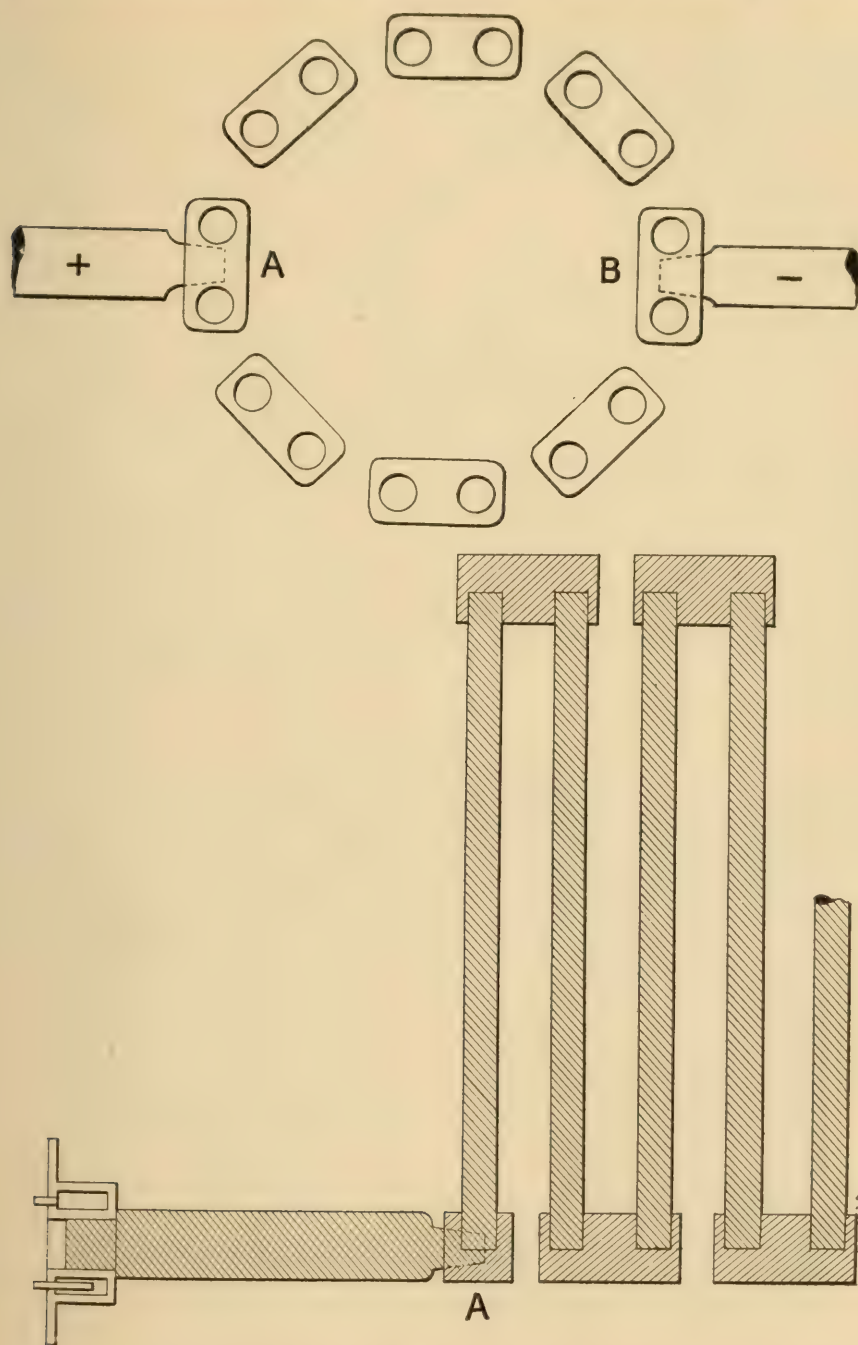
Fɪɢ. 1.

the heat generated in the resistors. The importance of good thermal conductivity of refractories is often overlooked, *e.g.* in externally heated muffles, crucibles, &c.

In the following table are given the particulars of a run on the furnace, using charges of 90 lb. of nickel-silver scrap :

First Heat.

Time from Start.		Current.	Voltage on Furnace.	K.W. on Furnace.	Remarks.
Hrs.	Mins.	Amps.			
...	...	200	64	12·8	Crucible put in.
0	30	240	71	17·0	
1	0	280	68	19·0	
1	30	300	64	19·2	
2	0	310	60	18·6	
3	0	310	60	18·6	Melt finished and removed.

Second Heat.

...	...	280	65	18·2	
0	30	290	63	18·2	
1	0	300	61	18·3	
1	35	300	61	18·3	Melt finished and removed.

In the above test the times of melting were 3 hours and 1 hour 35 minutes for the first and second heats respectively, while the energy
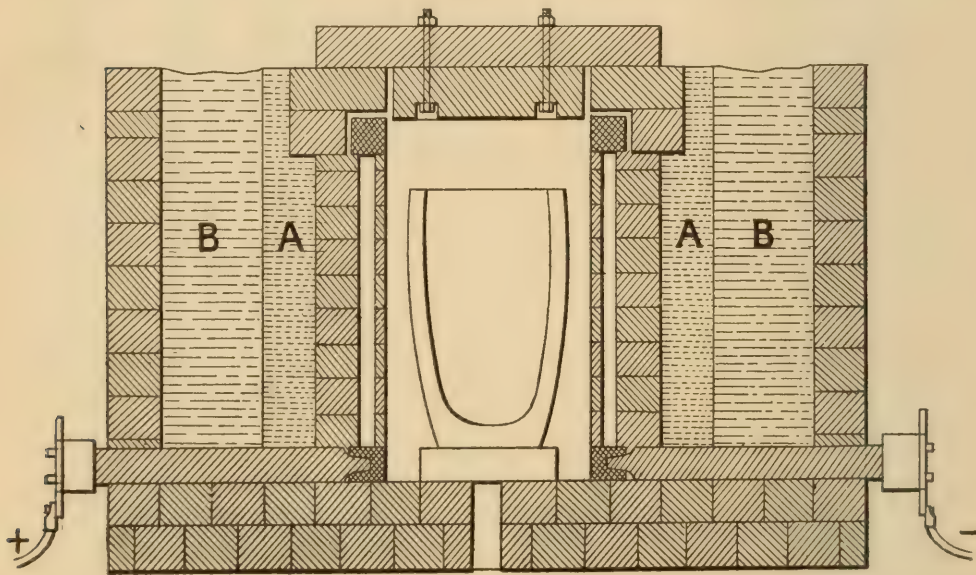
FIG. 2.

consumptions were 53·6 and 29·2 K.W.H. respectively per 90 lb. of metal melted.   On the basis of five heats per day (the furnace being started up cold every morning), and assuming the last three heats to require

the same energy consumption as the second, average energy per cwt.

$$= 34\cdot1 \times \frac{112}{90} = 42\cdot5 \text{ K.W.H.} ; \text{ cost at } 0\cdot8d. \text{ per unit} = 34d.$$

Although this cost is rather high (partly owing to the circumstances mentioned above), this would be largely compensated by the greatly increased life of the plumbago crucible. After several heats the (new) crucible used showed practically no change in appearance, not having suffered surface glazing or removal of graphite by oxidation.

Crucibles heated in gas furnaces flake very badly owing to the latter cause after a few heats.

Remembering that one could probably considerably increase the efficiency of the furnace on which the above estimate is based, the cost of electrical melting would seem to be not prohibitive, at any rate for special qualities of nickel-silver used for difficult spinnings, &c., which demand the highest possible ductility.

The actual thermal efficiency in the furnace was about 22 per cent. as compared with about 6 per cent. in the case of gas heating.

The further development of this furnace was postponed, owing to the difficulty of obtaining carbons in this country at the commencement of the War. A description of the work in this incomplete form is, however, given with the object of encouraging others to devote their attention to the development of a commercially practicable electric furnace.

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IDEALS AND LIMITATIONS IN THE MELTING OF NON-FERROUS METALS.*

By CARL HERING (PHILADELPHIA, U.S.A.).

PERFECTION in any art is best reached by placing before ourselves the maximum possible ideals with the limitations which they impose, and then approaching them as closely as commercial considerations warrant. Unless we know in what direction these ideals point we may be working on wrong lines ; and unless we know the limitations which perfection imposes we may be striving to accomplish the impossible without knowing it, or we may be endeavouring to make improvements which are not warranted by their cost.

The purpose of this paper is to summarize some of these ideals and limitations in the melting of non-ferrous metals, which should be borne in mind in endeavouring to improve present methods.

The directions to which perfection points are, to reduce (1) the loss of heat, (2) the loss of metal, (3) the number of bad castings, (4) the consumption of equipment (crucibles), and (5) the cost of labour and plant per lb. of good castings. As these are not all independent factors economy may sometimes result from increasing some if others are thereby reduced more greatly ; thus increased plant cost may save more in labour cost, and an increase in bad castings might even be warranted by the great saving of heat and labour due to working faster. The best combination of these economies is, therefore, not always a simple matter to determine, and of course it varies greatly with the local conditions.

One of the first things to bear in mind in all high temperature thermal operations is that insulation against loss of heat is, in practice, at best very poor. The ideal in this direction is the vacuum jacket of the Dewar thermos bottle, but this unfortunately is impracticable for metal melting. Hence as long as the metal is hot, just so long will this loss continue. But these losses

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depend not only on the thermal insulation, but quite as much, also, on the length of time during which they take place, so that reducing the duration of these losses reduces them in proportion. To obtain economy in heat, therefore, the ideal is not only to insulate as well as practicable, but also to heat and cast the metal in as short a time as practicable, and this ideal may be approached by having each lb. of metal heated for the shortest possible time. If, for instance, it takes two hours to heat and cast a certain large amount of metal, then each lb. of the metal loses heat during nearly two hours, while if this same amount of metal could be heated and cast in, say, four fractional parts, each in half an hour, the heat losses per lb. of metal would thereby be reduced to one-fourth of what it was, other conditions—to be discussed later—being here assumed to be the same. It is the total loss of heat per lb. of metal while it is hot which is the criterion.

From this standpoint the ideally perfect melting furnace, if such it can be called, is the electric fuse, in which the intended result is completed in such an exceedingly short time—a fraction of a second—that the heat losses during that time are vanishingly small, hence the thermal efficiency is practically 100 per cent.

With fuel heating, too great a rapidity of heating generally involves higher chimney losses, that is, a lower efficiency in heat transmission to the metal, hence a limit to the speed is soon reached ; but with electric heating there is no chimney loss, and the possibilities of rapid heating are therefore more encouraging. By heating with the electric arc there are high radiation losses from the arc itself, and from at least one and sometimes both electrode tips, as the arc must necessarily be above the pool of metal. But in heating the metal by its own resistance, that is, by the so-called resistance method, the heat can be generated below the surface, and in the metal itself, thereby eliminating all heat transmission losses. Neither chimney losses nor those due to radiation from the originator of the heat then exist ; there are therefore none of these restrictions, and extremely rapid heating becomes possible, being limited only by the size of the heat generating capacity which one is willing to provide ; and in the case of brass or zinc, by the volatilization of the zinc in the part in which the heat is set free. By the

resistance method, therefore, the ideal represented by the electric fuse can be approached more closely.

Small high-speed furnaces are, therefore, from this standpoint, an approach to the ideal.* In the writer's opinion it will in time become possible, for light castings at least, to melt in an electric furnace about as fast as one can cast, in which case the furnace would need to have a metal capacity of only enough for about two moulds. In that case it would be so small that it could be transported to the moulds, thereby saving the usual large heat losses in the transporting crucibles besides the heat losses in the crucibles themselves.

Although it is true that the heat losses per lb. of metal are reduced by shortening the time that the metal is hot, and that for this reason small high-speed furnaces would be more economical, it is also true that the larger the amount of metal in a furnace the less the *rate* of heat loss per lb., *i.e.* the loss per minute or hour, because with a large body of metal there is less surface per lb. which is exposed to heat losses than in smaller ones.† For instance, in a large furnace with a hemispherical hearth, the heat loss per lb. of metal, through walls having uniform insulation, is reduced to about one-half when the capacity is increased from 1 ton to 10 tons, and again to about another half of the latter, when the increase is from 10 tons to 50 tons. Hence, for this reason, the larger the furnace the better.

In choosing between these two apparently conflicting ideals, therefore, we must bear in mind the following points : (*a*) When melting is the only object then the metal should be kept hot the shortest possible time, hence there should be used as small a furnace as is consistent with the amount of metal required for one casting. (*b*) When there is involved refining, mixing, uniformity of alloying, the taking of specimens for analysis while melted or any other operation requiring time, then the larger the furnace the better.

At the writer's suggestion a large foundry which casts wire bars is now melting tons of metal in a small electric furnace only large enough to hold a little more metal than for one bar.

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* "Advantages of Small High Speed Electric Furnaces," *Metallurgical and Chemical Engineering*, April 1913, p. 183, by the writer.
† "Possible Reduction of the Power Consumption in Electric Steel Refining Furnaces," *Metallurgical and Chemical Engineering*, November 1911, by the writer.

Concerning insulation against loss of heat, it is true that the thicker the insulation the better, but it is also true that the outside surface, from which the loss takes place, also increases rapidly with an increase in thickness of the furnace walls, at least for the smaller capacities. Hence a thickness is soon reached beyond which it is practically useless to go.* In general, the nearer a body of molten metal (therefore the inside of the furnace or crucible) is to a sphere, the smaller the surface from which the losses arise ; the surface of a sphere is about half that of the circumscribed cube. Slightly in excess of an approximate hemisphere is therefore the nearest practical approach to the ideal for a furnace hearth.

While the thickness of the insulation is of importance, the nature of the outside surface seems to be a more important factor than is generally supposed, as there is sometimes a great resistance to the transmission of heat from a hot surface to the air. It is well known that a polished teapot will keep the tea hot longer than one with a dull finish. The resistance from a silver-plated surface is especially high, but silver-plating or polishing the outside of a furnace would be impracticable. White-washing, however, is a simple matter, and the fact that experienced foundry-men sometimes do this for their own comfort shows that the additional surface insulation produced thereby must be quite appreciable. Another practicable method would be to cover the outside with several superimposed layers of thin sheet iron with the natural polish obtained in their final rolling. Each of these surfaces would add its surface resistance.

Heating the outside of a furnace with a cheap fuel is another method, and was important enough for an electric furnace to be patented by a certain party after the present writer had called attention to it.

Over-insulation is also possible, because the checking of this flow of heat will cause the furnace temperature to penetrate more deeply into the interior of the walls, and this might cause trouble. For instance, the arched roof of an arc furnace can be prevented from collapsing only by actually increasing the loss of heat through it, that is, by insulating it as little as possible.

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* *Vide* the writer's paper on " Heat Conductances through Walls of Furnaces," *Transactions of the American Electrochemical Society*, vol. xiv. p. 215.

Water-cooling, which might be termed negative insulation, must sometimes be resorted to in order to guard against over-insulation.

Superheating of the metal is one of the important causes of the consumption of much of the heat which could be saved. Foundrymen have the habit of attributing most of their bad castings to the metal not having been hot enough,—after the proof of their claim no longer exists. While there is no doubt that lack of fluidity will give rise to bad castings, it is no doubt also true that to the supposed lack of superheat is often attributed that for which it is not responsible ; excessive superheating is frequently a useless waste of heat. Superheating is often resorted to merely as a convenience to the foundrymen, as they then do not have to work so fast.

Superheating is expensive in the cost of the high temperature heat, and with zinc alloys there is, in addition, the loss in the volatilization of some of the zinc, which means not only a loss of metal but also loss of the high temperature heat required in volatilizing it. The heat consumption for superheating involves the specific heats of molten metals, which unfortunately are generally not yet known, or are known only crudely ; a determination of them and of the latent heats of fusion is sorely needed in order to be able to estimate what these losses are. They are probably much higher than is generally supposed. In the writer's experience with a large electric brass furnace, the cold metal was melted rather quickly and efficiently, but the high superheating which was thought by some to be necessary, took quite long in comparison and was produced at a lower efficiency. For molten iron the specific heat is known to be considerably higher than for solid iron. With fuel heating this high temperature heat is less easily got into the metal as the temperature of the latter rises.

Much of the usual superheating is merely to supply the heat lost in transit from the furnace to the moulds ; this part of the superheat could, therefore, be economized by reducing these losses. Much heat can no doubt be saved by lower superheating, besides the accompanying saving in furnace lining, crucibles, zinc, &c. The ideal way of doing this is to cast directly from the furnace into the moulds. If the moulds are of metal, as in casting bars or ingots, they may readily be brought to the furnace, and if

made of sand the casting can be done without jarring them, either by floating them on a water channel, or by mounting them on a sort of carrousel. With a small, high-speed electric furnace it would not be impracticable to bring the furnace to the sand moulds. Heating the moulds, especially when made of metal, also saves some superheat, as it then costs less for that heat than if it be supplied at high temperature from the superheat in the molten metal.

Superheating may sometimes be done more economically by rapidly heating the stream of metal while it is being poured out of the furnace into the moulds ; the metal is then superheated for only a fraction of a second and its superheat need then be less because it loses practically no heat in that short time. This might be done by powerful blast flames along a prolonged channel ; or it might be effected electrically by causing the metal to flow through a carbon or graphite tube heated by resistance, or by passing a large, low voltage electric current directly through the flowing stream.

Superheating is sometimes resorted to for refining purposes ; viscous metal retains the dirt and other suspended impurities, hence by making it very fluid these impurities will rise into the slag or dross. It is an expensive way of refining but may sometimes be the simplest method. In a certain type of electric furnace this kind of mechanical refining is accomplished very rapidly and thoroughly by a peculiar, strong, upward circulation of the fluid metal, produced electromagnetically, and it is quite surprising to see the large amount of foreign matter which is thus brought to the top and which ordinarily would remain suspended in the metal. Ingots cast from scrap metal cleansed in this way are preferred by those who remelt them for castings. The dirtiest kind of old scrap metal refined by this so-called " electric boiling " casts into clean ingots with a fine fracture.

Melting in a partial vacuum, which becomes possible in some types of electric furnaces, may also tend to produce some refining, as it draws out suspended gases and may reduce the boiling points of some of the impurities enough to eliminate them by volatilization ; but for brasses this would greatly increase the loss of zinc by volatilization.

It is said that metal loses in quality every time that it is

remelted.   Provided that the proportions of the alloy have not been changed by the remelting, it is the writer's opinion that the deterioration is due merely to the metal becoming dirtier each time, largely with oxides, and that, therefore, if these suspended impurities can be cleaned out, the remelted metal would be as good as the original.

Flaws in the interior of castings are most probably due to such suspended impurities, chiefly metallic oxides.   A theory about brass seems to be that copper alone is known to contain some of its oxide in solution, and that the addition of zinc reduces this oxide, thereby forming an oxide-free alloy.   But the oxide of zinc thus formed in the metal, and which seems to be a suspended impurity as distinguished from a dissolved one, must then be removed, and as it readily floats, it will stay on the top after it can be got there.   When oxides are reduced in the metal by carbonaceous materials or by carbides, thereby forming the oxides of carbon, which are always gases, bubbles are necessarily produced which may be at least one of the causes of blowholes.

The losses of zinc in brass could be reduced in several ways : (1) By reducing the amount of superheat.   (2) By heating only from the bottom, so that the volatilized zinc condenses again in the cooler upper layer ; the electric arc furnace which necessarily heats only from the top, encourages this volatilization of the zinc.   (3) By heating under pressure, a method which is possible only in specially constructed electric furnaces ; though the data is not definite it seems that every atmosphere extra pressure increases the boiling point of zinc about $100°$ C.

The writer has noticed frequently that when solid metal is immersed in liquid metal it takes up heat from it very much more rapidly after it has become " wetted " by the liquid metal ; there seems to be a very high resistance surface film around the cold metal when merely in contact with, or floating on, liquid metal, hence when this film is broken or destroyed by wetting, this high resistance is broken down.   Agitation and forced submersion, which tend to wet the cold metal, will therefore increase the speed of melting and diminish the temperature of the hot metal necessary to get the heat into the cold metal.

If a curve be drawn showing the costs of producing a B.Th.U. at various temperatures by means of combustion heat, it will

be found that the cost rises slowly at first, for the lower temperatures, but very rapidly for the higher ones, such as those required in the refining of steel, the temperature finally reaching a maximum.   Too great a draught (four-fifths of which is useless and heat-robbing nitrogen) may supply more air than the fire can heat and it therefore cools the fire, as is illustrated in the blowing out of a candle flame. With electric heat, however, the corresponding curve is very different, being more nearly a straight inclined line and up to temperatures about double the maximum obtainable by combustion. For the lower temperatures the cost is greater, but for the higher ones it is less. The two curves intersect, hence the cheapest method is to generate the low temperature heat (up to this point of intersection) by means of fuel, and the higher temperatures electrically. In practice this means preheating the cold metal with fuel heat, say up to, but not above, the point where rapid oxidation takes place, and then melting and superheating this preheated metal electrically.

It is generally true that for the lower temperatures electric heat is more expensive per B.Th.U. than fuel heat, but it is a mistake to consider this to be the criterion. What is wanted is the least cost per lb. of perfect castings, and there are many other items which enter into the calculation besides the cost per B.Th.U. If electric heating diminishes the heat losses, the labour cost, the loss of zinc in brass, the crucible consumption, and increases the quality and uniformity of the metal, the perfection of the castings and the capacity of a plant, it may certainly be wise economy to pay more for the necessary electrical energy.

NOTE.

METAL MELTING IN A SIMPLE CRUDE-OIL FURNACE.*

By H. S. PRIMROSE (National Forge and Foundry).

Not every locality which has been selected for the large-scale melting and production of non-ferrous metals and alloys has been favoured with the possession of a high-pressure or cheap gas supply to facilitate operations. Many firms have therefore been content to purchase various forms of fixed or tilting furnaces of the oil-fired type and found them satisfactory. The chief difficulty with the majority of these, however, has been to retain or obtain the services of sufficiently skilled workers to operate the larger sizes so as to maintain uniformly good results both in the composition and strength of the castings and billets produced.

The writer has been privileged to assist in the evolution of a very simple and efficient type of fixed oil-furnace introduced by the Crittall Manufacturing Company for Government work, chiefly in connection with the rapid production of various grades of brass. The design is exceedingly simple, and permits of the use of unskilled labour throughout in its operation. The working drawings (Fig. 1) are re-produced to scale ($\frac{3}{4}$), and show the plan and several elevations of a single furnace, which is the left-hand unit of a pair of similar furnaces.

Construction.—The furnace proper is constructed of the simplest engineering materials. The outer shell or casing is made of mild steel plates bolted together to form a rectangular box, the height of which may be varied to take large or small-sized crucibles. The one illustrated is capable of holding 100 up to 200 lb. pots, their elevation in the furnace being governed by the thickness of stool employed to raise them from the floor brick. The lining is of ordinary firebrick set in ganister to leave a circular opening, the corners between the lining and casing being packed with sand as an insulating material.

The top of the furnace consists of two cast-iron plates resting on the top ring of firebricks and leaving a circular opening over which the furnace cover is placed during melting. The platform for the work-men is conveniently made of chequer plates, carried round all four sides of the furnace on channel or angle bars. This top also serves as a runway on which to move about the two-wheeled lifter for the furnace cover, which consists of a circular flat firebrick with a con-veniently small aperture in the centre. The cover is bound round with a stout band of iron which serves to hold it together, and to enable it to be moved aside by the prongs of the lifting carriage.

It has been found that the best arrangement is to have the whole furnace above the floor level, so that no pit or special foundation is necessary, and the construction and keeping clean of flues are com-pletely done away with. In the event of a crucible cracking in the furnace whilst full of molten metal, there is no difficulty in removing the spilled metal through the frontal opening, which is usually, in working, kept closed by luting in a firebrick.

Air Supply.—The space in between each pair of furnaces can be utilized in conveying the necessary pipe lines for the air and oil supply close up to the opening of the burner brick. Valves are of course required to regulate the inlet of each, so that the correct pulverizing of the oil into a suitable spray is effected to give the right flame to completely envelope the crucible and have a small flame protruding from the cover opening.

The shape of the special burner brick allows the oil spray to spread out in a conical fashion, and, igniting on entering the furnace with a tangential motion, it causes the flame to sweep round in the annular space between the furnace walls and the crucible before passing out at the central opening in the firebrick cover. By using a single burner brick of the required shape, and also by having the firebrick slab for the floor of the furnace in one piece, there is no chance of leakage or escape of unconsumed oil, and as it is thus all burned inside the furnace, great economy in the heating power results, and uniform time of melting may be relied upon.

The form of oil-burner used depends upon what type of air-pressure plant is installed in the works. Where compressed air is already in use, it must be reduced in the foundry to not more than 25 lb. per square inch effective pressure at the burner valve. The burner must then be of the special high-pressure design which is found to be ex-ceedingly effective in producing the necessary pulverizing action on the heaviest types of crude oil employed, and in this way high economy in melting may be secured. Such low figures as 1·5 gallons consumpt for each hundred pounds of brass melted can be consistently maintained. The slightly increased cutting action of the high-pressure burner flame, both on the furnace lining where carbonization is likely to result, and on the crucibles themselves, makes this extreme saving of oil a question-
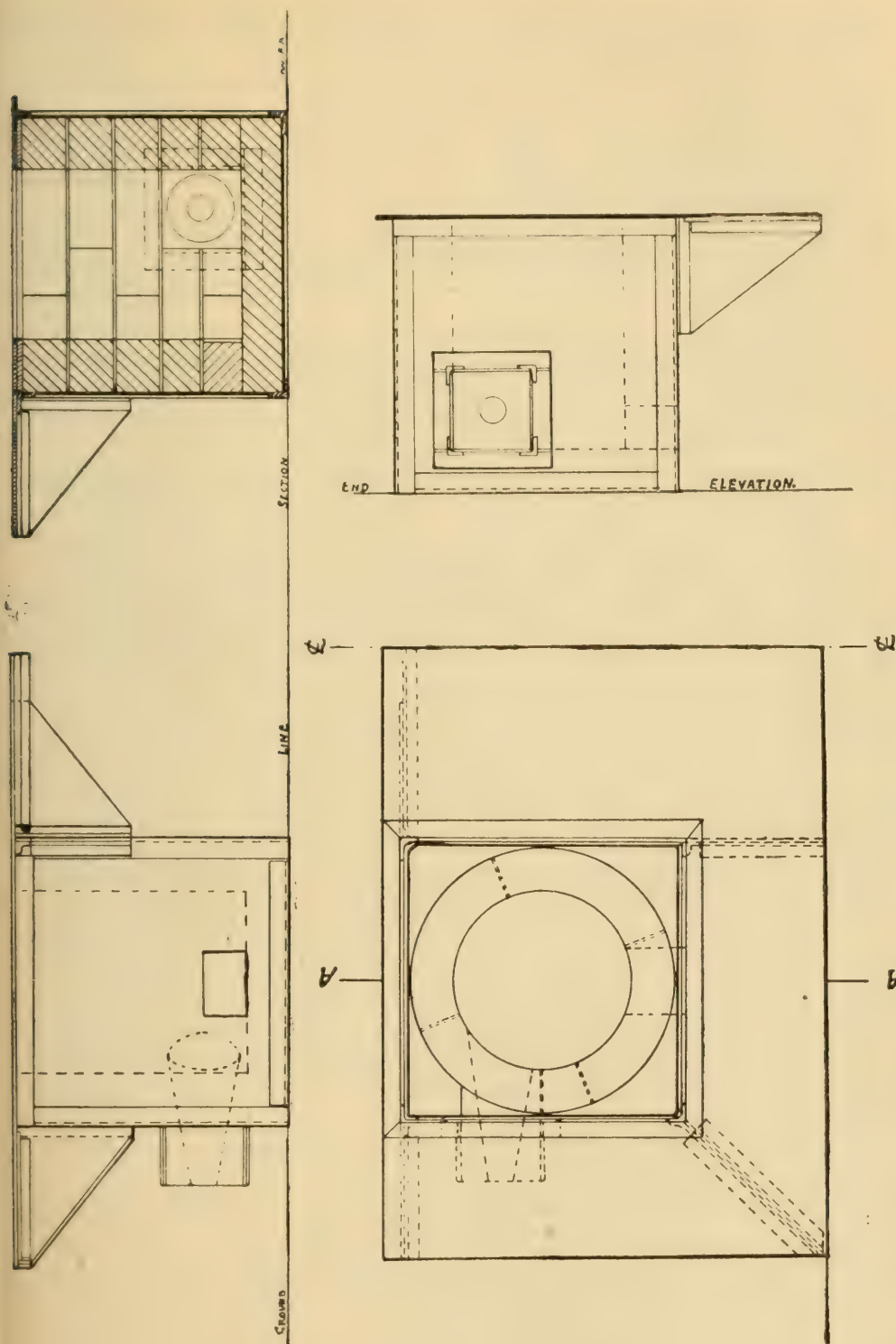
Fig. 1.—Simple Crude-Oil Furnace. Scale 1 inch = 2 feet.

able advantage in view of the short life of the crucibles and the more frequent patching required for the furnace lining.

Most satisfactory results have been obtained with the use of low-pressure burners, which can be used in cases where no high-pressure air system is in vogue. Small high-speed electric fans capable of producing about 12 oz. air pressure (*i.e.* from 20 to 22 in. of water-gauge) can be readily employed to work four furnaces simultaneously. The only precaution to be taken in such a case is that the furnaces should be started up from cold not more than two at a time, and those which are not immediately in use at any period can have the air supply cut off separately.

The oil consumpt in this method of working is slightly more than two gallons per 100 lb. of metal melted, but against that must be off-set the advantage of being able to melt with perfect regularity against time, as not more than thirty-five minutes are required to completely melt and pour 100 lb. of brass. 200 lb. charges require only 50 minutes to 55 minutes.

Advantages.—In addition to the advantage of being completely operated by unskilled labour, these furnaces have the obvious advantage of being easily removable, as they can be set down anywhere on a reasonably smooth floor. Besides being exceedingly easy to repair, they are constantly under the most complete control, simply by regulating the air and oil inlet valves. Their first cost is not great, and repairs are a very small item in their running. A large number have been in continuous operation night and day for over a year without any necessity for relining, and only slight attention to the walls in the way of patching with ganister has been needed. They are not nearly so destructive on crucibles as the various forms of gas flame employed in melting funaces, and the ever-present trouble of clinkering as with coke-firing is completely done away with. The only resemblance to cleaning which must be attended to, and that only on occasion when the correct air quantity has not been maintained during a run with very heavy or viscous fuel oil, is the deposition on the furnace wall opposite the burner of small accretions of solid carbon. It should never be allowed to interfere with the proper circulation of the heating flame, and the deposit must be barred off and removed when the crucible is withdrawn for pouring.

With 100 lb. pots there is no difficulty in withdrawing the crucible full of molten metal by hand, but when 200 lb. pots are used it is advisable to resort to a mechanical aid such as the quadrant lifting arm with a chain to hook on to the basket lifting tongs. This very much lessens the chances of accident and minimizes the effect of unsteady lifting out when manual labour alone is employed.

Melting Results.—In a properly organized brass foundry all mixtures are controlled by analyses, and the charges accurately weighed out, after briquetting if necessary. In this way it is quite feasible to do without any fresh copper. Complete returns are kept of the work and

output of each shift, and these may be abstracted for each grade of metal made. The following table represents one month's output of " G " metal only :

Metals melted :

Zinc		65,920 lb.
Cartridge cases		349,813 ,,
Swarf		709,218 ,,
Scrap		357,549 ,,
	Total	1,482,500 lb.

Flux used, 7,412 lb.
Aluminium deoxidizer, 920 lb.

Foundry Production : Number of melts, 14,825 of 100 lb.

Billets produced, 124,855 =		1,312,225 lb.
Scrap and spilled metal		26,539 ,,
Metallic shot recovered from foundry dross		73,920 ,,
	Total	1,412,684·lb.

Melting loss = 1,482,500 − 1,412,684 = 69,816 lb. = 4·7 per cent.*
Number of furnaces working, 18 to 22.
Total oil consumed, 32,599 gallons.
Oil consumed per 100 lb. of metal melted, 2·2 gallons.

* The amount returned as loss is somewhat in excess of its actual value, as the weight of metallic shot recovered (33 tons) represents an average of only 60 per cent. of the total dross produced and treated by simple washing. Further treatment by concentrator revealed nearly 30 per cent. more metal to be got out.

NOTE.

A NEW PRODUCER GAS-FIRED CRUCIBLE FURNACE FOR METAL MELTING.*

BY T. TEISEN, B.Sc. (BIRMINGHAM).

THE furnace of which some brief particulars are now given was invented by the Danish civil engineer, Axel Hermansen of Ingelstad, and is the result of several years' experiments. The scarcity of fuel and metal, and the consequential high prices of these commodities in Scandinavia as compared with Great Britain, made it necessary to build a more economical furnace than the type ordinarily used, with a view to compensating, as far as possible, for the otherwise high cost of production.

The first two furnaces were built by the inventor in 1913 at the Swedish metal works, Svenska Metallverken, Vesterås, for the melting of brass and alloys. Ordinary coal is used as fuel, and is fired in a gas-producer built in the furnace. It is worked on the Hermansen Recuperative System, which is now used in about 3500 furnaces of different kinds. This system, used for the preheating of air or gas, has in many cases displaced the Siemens' Regenerative System, which is more complicated and expensive. The main differences between the two systems are briefly : Siemens' Regenerative System for preheating air or gas is discontinuous, as the direction of the air and gas passing through the regenerator chambers—at certain intervals—is reversed, while the Recuperative System is continuous, the air and gas always passing the same way through the recuperator, which latter conducts the waste heat from the burnt gases continuously through the sides of the recuperator tubes to the secondary air.

The gas is conducted from the producer, P (see Fig. 1), to a central burner, B, where it meets the highly preheated air from the recuperator, R, thus being burnt in the combustion chamber, in which six crucibles of ordinary size are placed in a circle. The gases passing round the crucibles are led from here through passages to the recuperator, and through that to the chimney.

The crucibles are lifted by means of a pair of tongues, T, through an opening at the top of the furnace, which is kept on a level with the working floor, just as pit furnaces.

The official trial in Vesterås during one week in August 1914 showed

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* Presented at Annual General Meeting, London, March 22, 1917.

that the fuel consumption was 19 per cent. of coal, including the coal used for keeping the furnace warm from Saturday noon to Monday morning. Previously about 38 per cent. of coke was used in the ordinary pit furnace. The crucible lasted about 35 per cent. more heats than with the coke furnaces. The loss of metal was reduced from about $2\frac{1}{2}$ per cent. to $\frac{3}{4}$ per cent. The saving of this large amount of metal is due to the following :

1. The metal is melted in a reducing or neutral atmosphere, therefore the loss by oxidation will be the lowest possible.

2. The metal lost by crucible breakage or by overflow will not
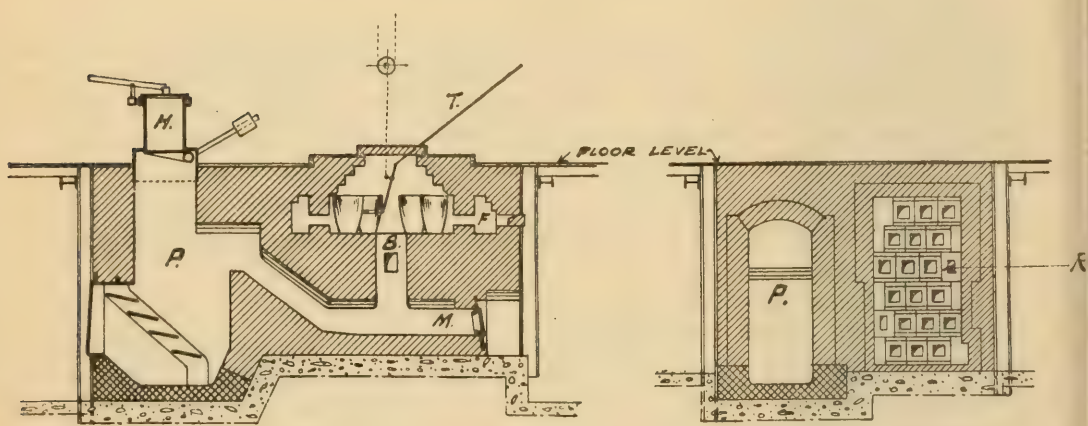
Fig. 1.—Hermansen Patent Recuperative Melting Furnace. Producer Gas-fired Type for Six Crucibles.

run down in the fire and mix with the ash, but is caught in a special pocket, M, from which it can be taken out in a perfectly clean condition and charged in the crucible again.

3. The temperature in the furnace can be easily regulated by means of air slides to any temperature required.

At Finspong Metallverken, where this furnace has also been working since 1915, the coal consumption was 18 per cent., equal to about $3\frac{1}{2}$ cwt. for 1 ton of metal (70 : 30 brass) melted. The furnace gave then about 14 charges, each half a ton, in 24 hours, equal to a production of about 7 tons. The loss of metal was reduced to $\frac{1}{2}$ per cent. These latter figures were the result of about six months' running.

A number of these furnaces are now running or under construction for many leading works in Scandinavia and the Allied countries.

METAL MELTING DISCUSSION.

Sir George Beilby, LL.D., F.R.S., President, said that he took it that the object of this discussion was to bring out all that was latest and best in the present-day practice in the melting of non-ferrous metals. He thought that the Committee and the Secretary had been remarkably successful in bringing together the kind of papers which were likely to stimulate discussion of a practical kind. He believed that the desiderata in metal melting were speed, preservation of the molten metal from contamination by gaseous or solid impurities, strict control over the temperatures of melting and pouring, and economy of fuel, labour, and repairs in the operation.

Sir Thomas Rose, D.Sc., Vice-President, said that he was not really prepared at the moment to discuss these papers ; he had been hoping to be able to listen to other speakers before being himself called upon. On reading the papers he had been struck by the great advantages which seemed to be found generally in the use of ordinary town gas as compared with coke for metal melting, whether it were in the rather large pot which was used at the Mint or in the somewhat smaller pot in operation at some of the other places. Unfortunately the data were insufficient to enable a comparison to be made between high-pressure gas and low-pressure gas for melting purposes. Mr. Walter, apparently, was in a position to furnish comparative data between high-pressure gas and low-pressure gas, but he had not done so in his paper. It was somewhat difficult to compare the data which Mr. Walter had given with those concerning low-pressure melting in other places as shown by other contributions. One would suppose—though he was putting the point as a question, as he desired to elicit information—one would suppose, if one tried to compare Mr. Walter's gas consumption with that at the Mint, that high-pressure gas gave a rather higher gas consumption for metals of similar character than did low-pressure gas. On p. 198 the author, Mr. Walter, gave the average gas consumption per lb. of metal melted for brass as 7·6 c. ft. That compared with about $5\frac{1}{2}$ c. ft. at the Mint for various alloys, which included about 25 per cent. cupro-nickel, and probably none of the alloys were so easy to melt as brass. It was not necessary to have high-pressure gas for cupro-nickel ; but he took it that when one came to higher temperatures, higher pressures of gas or air would begin to come in.

One question that he wished to ask Mr. Thornton concerned the use of flux. The author referred to a little flux with charcoal for preventing absorption of sulphur and furnace gases. Could he say

how much " a little flux " was ?　He also would like to know what sort
of mould he used for casting.　His, the speaker's, own experience
with flux had been that it was rather difficult, in narrow, upright iron
moulds, to prevent some of the flux from mixing with the metal and
making the casting unsound near the top.　Doubtless it ought to be
skimmed off.　But when one used a small amount of flux, there did not
seem to be anything which one could skim off.　He hoped the author
would be able to give some further information on that point, because
the use of a flux instead of charcoal, to keep away furnace gases, was
indicated if it were practicable in casting thin strips.

Dr. R. S. Hutton, Member of Council, expressed gratitude to
Mr. Hocking for his account of many years' continuous working under
carefully controlled and recorded conditions.　He felt that Mr. Hocking
had rendered a great national service in publishing this paper, which
brought home clearly to those engaged in the commercial melting of
non-ferrous alloys that the gas-melting process had been developed
beyond the experimental stage.

He would like to sound a word of warning to the gas interests.
Many people connected with the gas industry would no doubt welcome
the wide publicity which these papers would have, and conclude that
coal-gas melting of non-ferrous alloys had come to stay.　He would
like those gas interests to note, however, that commercial requirements
demanded a very much better service of gas than was generally obtain-
able at the present time.　As a consumer he felt strong resentment
against the undue advantage which the gas industry had taken of
war conditions.　The low calorific standard, which was spreading
all over the country whilst large users were too busy to oppose it, and
the very irregular pressure of the gas supply, were far from what was
required, and unless the gas interests took more trouble to study the
needs of the consumer the adoption of gas melting could not progress,
as would now appear possible.

Another desideratum for gas-furnace work was a simple device
for measuring the gas and air supply to each individual furnace.　He
had always felt sadly impressed with the way in which gas was wasted
in gas-furnace work.　The workmen who eventually had control of the
furnace were generally skilled in quite a different branch of work,
and had the crudest ideas of the properties of gas and its control.　In
fact the furnace was frequently regulated by noting some indirect
property—for instance, a peculiar sound or a flame emerging from some
fissure.　In some other gas-furnace work he had been doing lately, he
had had the advantage of using a very simple device based on a
" Brabée " tube and gauge, which enabled the flow of gas and air
to be accurately determined, and this method showed great promise
of providing a simple indicating device of general use for furnace
work.

The ideal of running a battery of gas furnaces with central con-

trol, similar to the main switchboard control of electric undertakings, should be easily accomplished, once a suitable device of this nature has been perfected. He could confirm, from work in another direction, Messrs. Thornton and Hartley's remarks on the value of preheating the metal, and was particularly interested in the points brought out in the paper by these authors. Further details were required of the construction of their furnace, and particularly of the gas and air pressure used with their blast-burner.

Mr. H. JAMES YATES (Birmingham) remarked that he had been very interested in Mr. Walter's paper regarding high-pressure gas. The figures given by that gentleman confirmed those which he had himself found in high-pressure gas work he was associated with over a period of years. On p. 199 the author gave, for cupro-nickel, an average gas consumption of 9·4 c. ft. per lb. of metal melted ; that was with high-pressure gas. With gas at ordinary town pressure, and air under 3 lb. pressure, that metal could be melted, in a similar sized pot, with anything from 5·8 to 6·7 c. ft. per lb. Coming to brass, Mr. Walter, on p. 200, gave a consumption of 6·2 c. ft. of gas per lb. of metal melted. That was for 72 : 28. With a burner under town pressure of gas and 3 lb. of air, it could be done with 2·9 ; in fact, he knew an instance where the furnaces were running regularly with 60-lb. pots on a consumption of 2·5 c. ft. per lb. of metal melted throughout the day's run. With regard to the life of pots, with the burner and furnace he had already mentioned they would consider it very poor practice if the melts were fewer than 80 per pot. High-pressure gas was not without some points in its favour, but in addition to other disadvantages, it was a costly plant to lay down, particularly on account of the need for compressing the gas where high-pressure gas was not available.

Coming now to Messrs. Thornton and Hartley's paper, their figures were interesting ; but one could have wished that they had been in a position to give the results of commercial everyday practice instead of merely the results of experimental work in their own laboratory. Those authors gave the consumption as 4·93 c. ft. per lb. for the first heat in a series of six, down to 1·4 for the last, but considering that the gas was of a net value of 555 B.Th.U., and that already alloyed ingots were melted instead of virgin metals, the consumption for the first heat could not be considered by any means the lowest attainable. On the other hand, the subsequent figures going down to 1·4 were too low to be maintained in commercial practice, although he knew an instance where the men, who had no previous experience whatever of gas furnaces, and who, not in any mere special or "fancy" test, but working under commercial conditions, got their heats down to 1·49 c. ft. per lb. of metal melted. He hesitated to give those figures, however, because the circumstances were exceptional.

He considered that Messrs. Thornton and Hartley's paper was a

useful one, because they had, at great trouble, looked up much reference work, and had included it in the paper for the use of those who did not happen to be familiar with past furnace practice. He would have liked those authors to give practical instances where the particular type of furnace referred to was run on a commercial basis. For his part, he knew of a number of cases in various parts of the country where the consumption was remarkably low, being for 72 : 28 brass 2·4 to 3·5 c. ft. per lb., and for pure copper from 3·0 to 4·8 c. ft. per lb., while for cupro-nickel the figures were as low as 5·8 c. ft. per lb., the highest being 8·5 c. ft. per lb. of metal melted.

Mr. L. C. HARVEY (London) said that Dr. Hutton had referred to " the visual flame method of ascertaining when a gas-fired furnace is running all right." This visual flame method was, in his opinion, the most practical test one can have. In Mr. Walter's paper the author referred to the fact that " one must have dampers in the flues in order to control the gas consumption and the proper working of the furnace." If there were no damper in the flue, and there were a heavy " pull " from a large chimney, the chimney was practically exhausting the furnace the whole time, and a lot more gas was therefore used in the furnace than was needed. With a damper in the flue, and a small hole in the furnace cover, a uniform positive pressure could be maintained inside the furnace ; so long as a test flame issued from that hole, it was known that a reducing atmosphere, and not an oxidizing atmosphere, was present in the furnace. From the foundryman's point of view, this was one of the best and simplest means of showing when a gas furnace was being properly heated.

With regard to Mr. Brook's table of figures for melting costs, &c., which appeared on p. 173 of his paper, he wished to criticize these costs, for they would be published in the Journal of a technical Society, and would be referred to by engineers wishing to arrive at the comparative cost of coke, oil, and gas. To begin with, a charge of 30 lb. of yellow brass did not represent a test on commercial lines ; it was more in the nature of a laboratory experiment, and it would have been much better had the test been carried out with, say, 200-lb. crucibles. Next, the three furnaces—coke, oil, and gas—were not run at anything like their full capacity. He believed he was right in saying that the oil furnace was one constructed to take a 120 lb. crucible ; the coke furnace was an ordinary pot-hole for a crucible of 90 lb., and the gas furnace was also made for a 90-lb. crucible. (Brass capacities in each case.) The oil used to melt the 30 lb. of brass in the 120-lb. size furnace was almost as much as that required for melting steel. The fuel consumptions mentioned, especially the oil consumption, are therefore somewhat misleading.

The fuel consumptions recorded for this particular test were :— for coke furnace 66 per cent., which equalled a furnace efficiency of only 3 per cent. ; oil, 4·1 gallons, or, say, 39 per cent. by weight, giving a

furnace efficiency of 3·4 per cent. In the gas furnace, however, the consumption was 383 c. ft. of, say, 520 B.Th.U. net gas, the furnace efficiency being 13·1 per cent. If daily fuel figures for normal pit fire furnace melting 70 : 30 mixed metal were taken, a coke consumption of 30 per cent. would be required, equal to 7·7 per cent. furnace efficiency ; oil 20 per cent. by weight, or 6·6 per cent. furnace efficiency ; and 300 c. ft. of gas per 100 lb. of this metal should be ample, which equals a furnace efficiency of 16·7 per cent. Now considering tilting furnaces of, say, 600-lb. size which would melt 600-lb. charges of mixed metal with 10 per cent. overall coke consumption, the furnace efficiency became 20·1 per cent. ; oil, 8 per cent. consumption, giving an efficiency of 16·6 per cent. ; gas, 225 c. ft. per 100 lb. or 20 per cent. furnace efficiency.

(At the suggestion of the President, the speaker agreed to send the remainder of his reply to the Secretary.)

Dr. WALTER ROSENHAIN, F.R.S., Member of Council, said that he had been very much interested in these papers, and felt that they would prove to be of great importance. There were one or two points about them which called for a little consideration.

In the first place, if the claim made by nearly all the authors for the high efficiency of the gas-fired furnace were correct, he regarded it as surprising, because against the gas furnace one had, on fundamental principles, the cost of converting the fuel into gas. There was also the fact that in the ordinary gas furnace, driven with gas or air under pressure, one was sending up the chimney, or blowing into the open air, large volumes of heated gas, *i.e.* one was, by this means, throwing away heat. And the suggestion occurred to him— and it had been strengthened in listening to the last speaker—that perhaps the conclusions arrived at in these papers were principally due to the fact that the ordinary coke furnace was a very bad thing of its kind, rather than that the gas furnace was a very good thing of its kind. He would ask, Was it not possible to improve the coke-fired furnace, and increase its efficiency, so as to take advantage of its thoroughly good and useful characteristics ? The fact of using the whole of one's fuel without having first to convert it into gas must be an advantage. The low thermal efficiency which some of the figures for coke showed must indicate a heat loss, which could perhaps be avoided. With regard to gas furnaces, they had proved absolutely superior to furnaces fired with solid fuel in the large furnaces used in steel and other industries where the regenerative principle could be applied, and attempts had been made to do that also in gas furnaces for melting non-ferrous alloys. But in connection with this question of " regeneration," it was well worth bearing in mind that it was of no use preheating either gas or air, if that were done by heat taken from the furnace ; it must not be done at the expense of the furnace

heat : it must be done by the heat borne by waste gases. If one put an air-heating jacket round the furnace chamber, one was really borrowing from Peter to pay Paul, and with no good result. That was done by certain of the furnaces on the market. True regeneration was a most efficient th'ng, and it could be done with coal-gas. There was no decomposition or trouble at all in preheating the air and burning the gas with air preheated in a regenerator, or preferably a recuperator. It could be done especially in melting high-temperature alloys of nickel ; it was proving quite a practicable thing.

With regard to the temperatures which were attainable, one of the authors had some doubt as to whether he could melt nickel or even cupro-nickel in a gas-fired furnace. It might be of interest to that gentleman to know that it was possible, with ordinary coal-gas, and air under pressure, to obtain a temperature considerably over 1650° C. That had been done in the laboratory, so far, and he was sure it could be done anywhere by the use of high-pressure air (at 80 to 100 lb. per square inch) used as an injector, and drawing in much subsidiary air and thus using the energy of the compressed air, not merely its volume. By this means one obtained a flame with which it was possible to burn a large amount of gas in a small space and obtain a very high temperature. A furnace of that type might prove of value when dealing with a special type of alloy which, he thought, had a future, nickel-chromium, and similar alloys requiring very high temperatures, such as 1400° C. for melting and handling.

There was another point regarding these furnaces to which he wished to draw special attention, one which had been ignored in the papers read—and he might be pardoned for thinking also of the other papers which were to come on at the evening meeting—there being only one possible exception to the omission. He referred to the question of the thermal conductivity of the materials of which the furnace itself was built. Much of the heat generated inside a melting furnace went not to the heating of the metal, but to the heating of the surroundings of the foundry, to the detriment of the powers of the furnace and of the comfort of the men. That could be, in large measure, avoided by a suitable design and by the choice of proper materials. Furnace designers required to know more about the properties of these materials, and to consider the choice of the correct ones. A material which was now becoming available for furnace construction, zirconia, afforded a very considerable protection against loss of heat by conduction through the furnace walls. That material, however, had to be used with some discretion, because by preventing loss of heat through the furnace walls, one increased the temperature of the inner surface of those walls, and so one's refractory lining, if it were not sufficiently refractory, might melt down and be destroyed. That the majority of furnaces stood up so well to their work was simply due to the fact that they were so efficiently air-cooled from the outside. He believed most gentlemen who had to deal with furnaces would agree

with that. When one began to make a furnace efficient, one found that the refractory employed was not good enough.

What had particularly interested him in Mr. Hocking's paper was his reference to the use of a wash of carborundum for the inner faces of the furnace. He, the speaker, could confirm that. It was a most valuable thing to do. It did protect even relatively inferior fire-clay linings from erosion, and particularly from that erosion which would cause melting down if a protection were not applied in that way. It was relatively cheaply applied, and it produced an important improvement in the furnace linings.

He wished to express his thanks for, and his appreciation of, the work of the authors of these papers ; and he hoped that in the future the Institute would hold discussions on other branches of the apparatus used in foundries and mills.

Mr. H. L. REASON (Birmingham) said that he had listened with a good deal of interest to Mr. Walter's and Mr. Brook's papers on high-pressure gas. From the papers which had been placed before the meeting, one would think the hearers would all go for melting by gas. He felt, as a new member of the Institute, somewhat nervous about going against the trend of such valuable papers, but as some of his predecessors had taken the opportunity of challenging gas to some extent, that fact had given him courage to voice his convictions.

He thought that, in considering whether one should use high-pressure gas or coke, it was necessary to attack the matter with an open mind. The first thing which appealed to one in considering high-pressure gas was the cleanliness and general tidiness of the foundry. Against the quietness of coke fires, one had the noise of the gas furnace ; he did not know whether many present had experience of the great noise, which practically prevented one hearing oneself speak. The economical aspect always appealed to them, as commercial men, when running a foundry. He agreed that good results could be obtained by experts, but one did not always find experts in foundries. It must be realized that when a man had to carry coke to a furnace, he would be careful to carry no more than was necessary. Against that, he could easily turn gas on in the case of a gas fire, and could leave it on. With regard to the air-blast furnaces, those which he had seen of that kind appealed to him most, because they did not make such a tremendous noise. From his investigations, gas furnaces seemed to score immeasurably over coke-fired furnaces when melting aluminium.

With regard to Mr Brook's paper, he noticed that the author used the word " expert " in all his cases with regard to oil, gas, and coke, and in making his comparisons he got coke at 24s. a ton placed against 10d. per 1000 ft. of gas. He, the speaker, believed it would be found that when gas was at 10d. per 1000 ft., coke was about 16s. a ton. By replacing the figure of 24s. by 16s. it gave a better idea of the comparative cost. He understood Mr. Brook had given the

cost of the crucibles with coke and gas as the same ; but it had always been drummed into him, the speaker, that one saved much on crucibles if high-pressure gas were employed.

In regard to the tests, he agreed with the previous speaker that Mr. Brook's tests would have been much more reliable if he had taken a 200-lb. pot instead of a 30-lb. pot ; the former would have been more of the commercial size. With regard to cupro-nickel, Mr. Brook's tests came out very badly with coke, but he thought Mr. Brook might have put some forced draught on to the furnace, and that would probably have shown a better result in regard to the speed of melting.

In taking out his costs for coke furnaces against gas furnaces, Mr. Brook made the cost practically the same, but did not include building chimney-stacks in connection with high-pressure gas furnaces. He had always understood good chimney-stacks were as essential for high-pressure gas furnaces as for coke fires. He certainly thought the comparative figures for coke and gas furnaces should be worked out by people with an open mind.

Mr. A. J. G. SMOUT (Birmingham) said he was particularly interested in Dr. Hutton's remarks on the variation in the pressure of the gas, inasmuch as this was one of the troubles of people who were using gas for metal melting. Mr. Hocking, on p. 156 in his paper, referring to the practice at the Mint, said that the gas was delivered at a steady pressure of 3 in. of water at the furnace, and yet, on p. 159, he talked about adjusting the quadrant taps in the event of variation of pressure of the gas. He, the speaker, would like to know if, at the Mint, any trouble was experienced owing to the variation of gas pressure ; if so, had any attempt been made to use a gas governor and so obviate the variation in the pressure of the gas. If not, what steps had been taken at the Mint to avoid such variation ? If one were going to wait until the gas pressure dropped (*e.g.* if one were registering $\frac{2\cdot5}{1\cdot0}$, and the gas pressure dropped to $\frac{2\cdot0}{1\cdot0}$), a great deal of damage would be done before the quadrant taps could be adjusted, although the interval might only be five or ten minutes, because the flame changed, owing to the fall in pressure of the gas, from a reducing to an oxidizing one, and flaking of the crucible resulted.

Mr. Hocking, on p. 163, referred to Morgan Salamander crucibles of a special brand, suitable for use in gas-fired furnaces : he asked whether Mr. Hocking had the comparative figures showing the lives of that special " gas " brand and the ordinary crucibles in the gas-fired furnace ; also the figures for coke furnaces of this special " gas " crucible. It would be very interesting to know what were the comparative lives of the two brands of crucibles under coke and gas respectively.

On p. 160 of Mr. Hocking's paper, under the heading of furnace management, he recommended, when closing down, that the gas should be cut off first, and afterwards the air. In his, the speaker's, opinion, that was not good practice, because if one allowed air to enter the

hot furnace during the time the gas was cut off, not only was the furnace and its charge cooled down, but oxidation and flaking of the crucible ensued ; still, he would be interested in hearing the views of others on that point. Personally, he thought the best practice was to shut off both gas and air at the same time ; and he certainly saw no reason why that could not be done.

With regard to Messrs. Thornton and Hartley's paper, the figures given for gas consumption, on p. 226, were, in the speaker's opinion, very low, *i.e.* about 2 c. ft. per lb. of metal melted. It was necessary to remember that they were using a 70-lb. furnace only, and the gas consumption on that sized furnace was very much less than when dealing with what one might term a brass-roller's size, 150 or 160 lb. His experience was that the larger the size of the furnace, the greater the gas consumption per lb. melted. The figures given on p. 226 should be noted as applying to a 70-lb. furnace, otherwise people reading them might be misled. When reading about 2 c. ft. per lb. of metal melted, users might expect to get the same results with a 150-lb. furnace, but it could not be done. The speaker's experience led him to believe that with a 150-lb. furnace the figure was nearer 4 to $4\frac{1}{2}$ instead of 2.

There were also some misleading figures concerning the number of heats which a pot would give. It had to be remembered that this figure too varied considerably with the size of the pot and with the nature of the work being cast.

Under this heading, on p. 228, the authors state that they were getting 45 to 50 melts out of a 70-lb. pot. He thought it was due to the meeting to know whether that result was obtained in experimental work, or whether it was an average extending over a period of actual work. Could the figure here given be taken as actually representing works practice ? Or was it a test carried out by experts under very careful management ? He would also like to know whether the number of heats given by the pots was with sand-casting, or casting into chills. When casting into sand moulds a pot would give a much longer life, because the pot could be worn out to a much greater degree ; in fact, when casting into sand one could get seven or eight more lives than when casting into chills. These matters were important when considering these papers from the point of view of costs of gas *versus* coke-fired furnaces.

Mr. HAROLD HARTLEY, M.Sc. (Warrington), said that he would like to put one or two questions to the contributors of some of the other papers, but before doing so he wished to endorse Dr. Hutton's remarks with regard to the utility of Mr. Hocking's paper. Being concerned with the manufacture of furnaces, he felt that this record of work done with solid and gaseous fuel would be invaluable to him. To come to details, he was surprised at the large discrepancy between Mr. Hocking's gas consumption data, calculated per lb. of metal melted, and those

which Mr. Thornton and he recorded, a discrepancy which seemed large even after making due allowance for the fact that he and his co-author had dealt only with data obtained under test conditions, when avoidable wastage was eliminated and the appliance was worked at its maximum thermal efficiency. It was a surprise, he said, to find that neither at the Mint nor in the work of the Birmingham High-Pressure Gas Department had any attempt been made to preheat the metal or the fuel prior to admission to the furnace proper. The advantage of such preheating would be well emphasized by mentioning that it should enable a 30 per cent. saving of fuel to be effected, equivalent to a saving of £2000 to £3000 on the five years' gas bill of the Mint.

On turning to Mr. Hocking's data for gold on p. 152, it was noticed that, for an average of twenty-five successive melts per furnace, this metal was melted at a gas consumption of about 1·8 c. ft. per lb. On the other hand, on p. 163 an estimate of 7000 c. ft. per ton, or 3·1 c. ft. per lb. of gold melted, was given for commercial practice, an increase of over 72 per cent.*

This latter figure included remelted metal, which the author estimated at between 2 per cent. and 3 per cent. ; for the rest the discrepancy was attributed to the usual delays and accidents unavoidable in the ordinary routine of work (*vide* p. 168). Comparable coke figures were not given, but from a consideration of the data supplied in the introductory portion of Mr. Brook's paper it would almost appear that in the Mint work there had been a greater percentage wastage of fuel with the gas-fired than with the coke-fired furnace ; to some extent this was to be expected, as the rate of consumption of fuel was less in the latter case. He would like to ask Mr. Hocking if he could say whether this had or had not been the case.

It appeared from Mr. Walter's paper that 4½ to 5 c. ft. per lb. of brass melted represented the result obtainable under test conditions with his high-pressure gas furnace. If this were so, it seemed to him (Mr. Hartley) to be a somewhat high fuel consumption, even after making allowance for the absence of any attempt at preheating, and he would welcome a statement on this point from Mr. Walter. The foundry test quoted in Table IV. gave a consumption of 7·6 c. ft. of gas per lb. of metal as against 4·5 c. ft. per lb. obtainable under favourable conditions, roughly a 70 per cent. wastage of fuel. Further, on p. 204, Mr. Walter stated that in the melting of a 60 : 40 brass with his high-pressure gas furnace, " the gas consumption amounts to approximately 6 c. ft. per lb. of metal melted in the case of ingot, strip, and billet work," from which it was to be deduced that he regarded a 33 per cent. wastage of gas as unavoidable even in ingot work. Some of the results given by this latter author referred to short-period foundry

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* If it be assumed that only seven melts were made successively per furnace in ordinary practice as against twenty-five during the test, this would probably account for an increase of about 30 per cent. on the test consumption. [Footnote added subsequent to discussion.— ED.]

tests, and it would be of interest to know, if the author had the data available, what were the stand-by losses.

The results recorded in these two papers served, the speaker said, to emphasize in a very remarkable manner the necessity for efficient control of a rapidly working metal-melting plant. Surely a 70 per cent. wastage of gas could be avoided, and was really the exception rather than the rule.

One way of decreasing the wastage would be to employ, when practicable, a smaller size of furnace than had been customary with the slower-working solid-fuel furnace.

Both authors appeared to be inclined to allocate the wastage to stand-by losses and accidents—in other words, to what might be regarded under present conditions as unavoidable foundry wastage. He felt, however, that this was not the whole explanation, as it was difficult to imagine three hours out of every nine of the working life of a metal-melting plant being absorbed in that way. Was it not probable that a large proportion of the losses were due to inefficient working of the furnace ? If the gas and air supplies were not properly adjusted, not only were the flue losses swelled automatically, but a lower temperature was produced in the combustion zone, and this in its turn involved a decrease in the rate of transmission of the thermal energy to the pot, with a resulting fall in the efficiency of the appliance.

Mr. C. W. Speirs (London) said that a portion of the raw material used in the manufacture of crucibles was imported, and the question of future supplies, in view of the shipping difficulties, made the economical use of crucibles nearly as important as the economical use of food. What might, he thought, be of assistance in this connection was the system of giving a bonus for the number of heats obtained above the present average ; the system had worked well in many foundries, and the saving in crucibles as well as increased efficiency made it a matter worthy of consideration.

As one who was interested in crucibles for all types of furnaces, he had listened with great interest to what had been said. He did not think, however, that any one of the fuels—gas, coke, or oil—was better than the other ; each had its own good points. Much depended on the use they were to serve, and a great deal on the intelligence of the workman.

With regard to the question of turning the gas off, in the case of tilting furnaces, by leaving the gas on very slightly and turning the air off between melts, thus keeping the crucible hot and in a non-oxidizing atmosphere, one could enormously increase the number of heats obtained from each crucible.

It was true that the crucibles used by Mr. Hocking were special crucibles, but there could be no doubt that much of the improvement was due to the careful way Mr. Hocking looked after his furnaces.

Mr. J. Dewrance, Member of Council, said that the advantages of gas melting were so apparent that if only the difficulties could be overcome, it would be an enormous advantage to all foundries. One of the chief advantages was that the method saved the trouble and the losses due to the metal being mixed with ashes from the coke. Moreover, the gas method produced from the same space nearly double the amount of melted metal. Up to the present time, however, his foundry had not been able to overcome the grave difficulties which were in the way. They had tried, over a long period, 100-lb. pots and 400-lb. pots of all varieties of metal up to cupro-nickel, and the experience was that so long as the gas furnace was new and in good condition, the advantage was enormous ; the economy in the cost of melting was considerable, and the other economies were also very great indeed. But nothing could be got to stand the heat of the gas. When using coke, the coke was all the way up the crucible, and generating heat all the way up, whereas with gas its effect was nearly all in one place, and a much larger amount of heat was needed in that place in order to ensure it being great enough where required. There was nothing which would stand the impact of the flame from the gas so applied. As Dr. Rosenhain said, they were studying the matter of refractories ; and until some solution was found, he feared the gas furnace must wait, for it was not a practical method at the present time. And the difficulty of buying efficient refractories was great. Crucibles for gas furnaces had to be specially made, and were not reliable, owing to their liability to crack, especially the 400-lb. ones. If the heat in the gas furnace could be better distributed, and if the gas could be got to burn more as it did in the steel furnace, it would, in his opinion, be an improvement.

Mr. Shipley N. Brayshaw (Manchester) said that he had read all the papers which had been submitted with great interest. There were various particulars which he could give, and he had the figures with him relating to various tests, but as the time was so limited, he would send them to the Secretary as a memorandum, to be included in the report of the discussion.

In one large typical works at which the melting of cupro-nickel was carried on in large quantity, it was found that after the first melt the fuel consumption with a gas furnace was between 6 and 7 c. ft. per lb., using ordinary coal-gas at the usual pressure from the main, and in regular day-to-day work. At another very extensive works the melting of pure nickel was carried out over eighteen months, during which time they used coke side by side with gas, and they reported at the end of the period that the comparative costs were : coke, 4s. 2d. ; gas, 1s. 9d. He could scarcely have credited the figures, but they were given by the users, and for the period of eighteen months.

With regard to the life of the pot, after collecting statistics from a number of places, it was found that with gas-fired furnaces the average

life of the crucible extended to about 80 melts : he could give specific instances of crucibles which had stood for 120 melts in regular commercial use, and when handled by ordinary workmen. To show that the melting of metals by gas was a long way past the experimental stage, he could also give particulars of a large single plant burning 500,000 c. ft. per hour of water-gas, and nearly all on metal melting.

After Dr. Rosenhain's remarks, he was tempted to say that at Johnson Matthey's they found that a 500-oz. ingot of platinum began to run under the action of a gas burner although they only intended to heat it strongly for welding. The burner was similar to those used at the Royal Mint. He could tell Dr. Rosenhain that a few weeks ago he took the temperature in a furnace of about one foot cube inside, which was burning gas from the main with air at not more than 2 lb. pressure, and found it to be 1800° C. He had the Cambridge pyrometer, which was used for the reading, verified after the event.

With regard to the afternoon's papers in general, he felt that they needed to be standardized and brought to one level, so that comparisons could be made. The paper by Mr. Hocking stood out pre-eminently, and he thought that his contribution should be regarded as the standard, except in regard to the point that he paid 2d. per unit for electricity. The paper itself was a wonderful record. He had himself been accustomed to give the gas consumption in cubic feet per lb., but Mr. Hocking gave tons as his unit. One who melted 10,000 tons in five years had a right to talk in that way. Mr. Hocking gave all his results with respect to the metal finally obtained, and on p. 163 some very interesting figures were given, but his expression was " gross amount of metal melted." One might think from this that he calculated on the amount which went into the pot, as is the case in some of the other papers. On p. 168, however, the author said it was not so, for spillings, filings, rough ends, and faulty bars, are not included. One felt in reading Mr. Hocking's paper that he was not trying to make out a case. He did not stretch any result in order to make it look better, but he had everywhere stated the worst against himself. He would like to hear from Mr. Hocking what was the calorific value of his gas, and whether the figures for coke melting prior to 1911 should also be increased 2½ per cent., in accordance with the statement on p. 168. Also did he train men who had been accustomed to coke, and make them work with gas ? He had seen Mr. Hocking patiently teaching his men, and he felt sure some of the success shown was due to good instructions in the first instance.

He (Mr. Brayshaw) felt that the future in this matter lay not with high-pressure gas, with all its difficulties, and the disappointing figures which had been put before the meeting, not even with gas from the main, and air at 1 or 2 lb. pressure, but that melting would be done in the future with ordinary gas and air at only a few inches of pressure, not exceeding a 12-inch water column, and that would mean an enormous cheapening of cost, owing to the economy of plant. One would then use merely a rotary fan. With the developments which were taking

place, he thought foundry workers were on the threshold of great advances.

The PRESIDENT said that throughout the discussion it had struck him as remarkable that the original blow-pipe furnace of the laboratory had continued so long to supply the ideal for all the developments of gas melting furnaces which had taken place. Mr. Brayshaw's remarks, however, introduced a new note. He agreed with this speaker's remark that if they could not get any desired temperature by the use of gas and air at *moderate pressures*, they were not working on the right lines. In his own practice he had long ago abandoned the Bunsen types of burner or blow-pipe for the heating of furnaces and ovens in favour of a method of separate introduction of the gas and air into the combustion chamber at a relatively low velocity. The gas and air were both supplied under sufficient pressure to permit of their being measured into the combustion chamber with certainty and in the correct proportions to ensure perfect combustion. It was thus possible to maintain a slight positive pressure in the furnace and regenerator, and finally to discharge the products of combustion into the atmosphere without having to depend on the suction of a high chimney. Under these conditions even a steel-melting temperature could be maintained with the maximum of economy. It was the essence of this system that the gas and air should be delivered at a definite and uniform pressure. Apparatus for the boosting of the gas and air up to the necessary pressure of a few inches of water was neither costly to instal nor to maintain.

No mention had been made during the discussion of any attempts to control the conditions of combustion by the analysis of the spent gases; surely the fact that the larger the furnace the less efficient it became might suggest that exceptional losses were occurring in the escaping products of combustion.

Dr. WALTER ROSENHAIN, F.R.S., Member of Council, said that the papers dealt with a number of subjects not easy to discuss together. He would therefore deal with them one after the other. In regard to the paper relating to pit furnaces, he wished to refer to a point which he had raised that afternoon, namely, the question of heat losses in furnaces of that kind. It was a question of conductivity *versus* radiation. It was well known that if a furnace were erected above ground and built of fire-brick, an increase in the thickness of the walls would, up to a certain point, decrease the heat losses; beyond that point, however, any such increase in thickness would increase heat losses, because after a time the effect of the heat conductivity of the fire-brick, together with the increased cooling surface, was actually greater than the effect of the heat conductivity, radiation and convection that took place through the medium of the air. When a furnace was built into a pit in the earth, it was built into a material which was, relatively speaking, a good

conductor of heat ; and even if the covering could be described as insulating covering, the thickness of such covering would still be excessive. It would be well worth trying whether it would not pay—possibly it would pay handsomely—to put in a layer of heat insulation around the furnaces or groups of furnaces, in order to prevent the loss of heat into the surrounding earth. The next matter to which he would refer was the extremely interesting paper just read by Mr. Teisen. It was really surprising that a paper of that description should come as a novelty to the non-ferrous metal industries. The use of producer gas-fired furnaces, arranged for regeneration or recuperation, had become such a commonplace, in view of the necessity for economy—particularly in the glass industry, and also in certain regions of the steel industry—that it was surprising that the non-ferrous industries had not adopted it more extensively than he believed they had ; certainly he was not aware of many cases in which it was in use. That was a consequence of a sort of " water-tight compartment " existing between people who were working in different branches of technology. The brass-worker did not know much about the glass-worker or steel-worker, or at all events not as much as he ought. The actual furnace which had been described was a neat and convenient type, recalling to his mind some with which he had had occasion to work in connection with glass ; it was certainly a very efficient type. There was a good deal to be said in favour of the principle of recuperation as against regeneration, *i.e.* in favour of the continuous flow of the secondary air through a system of pipes or ducts heated by the flow, in the reverse direction, of the heated products of combustion. That method, provided the sizes were ample and that the recuperator pipes were made of a material of reasonably high conductivity, was an extremely efficient one, and one which avoided the complication and risks attendant on the use of reversing valves which were inevitable in the regenerative furnace. On the other hand, the construction was somewhat more complicated, because of the system of pipes, whereas in the regenerative furnace there was merely the stack of bricks and the chamber, and repairs in the case of the recuperative furnace would probably be more expensive. He was satisfied that the recuperative furnace could be worked extremely well, as he had recently had a small experimental furnace constructed, in which the recuperative system was adopted, with excellent results ; the fuel used was coal-gas, while a simple straight recuperator tube was employed.

The electric furnace was likely to be of steadily increasing importance to the metal industries ; it was already in use in the steel industries, and its future in the metal industries generally was, he thought, perfectly assured. His reasons for so thinking were many, but perhaps the most cogent was the increasing appreciation of the desirability of keeping the metals extremely pure. Specifications were becoming more and more stringent in regard to purity, and even where there was some hesitation in specifying purity, it was well understood that the

metals should be as pure as possible. In the electrical furnace an accurate control of the working temperatures of the metal right through could be realized, together with an accurate control of the atmosphere and gases surrounding the metal, which was essential to the high degree of success which should be aimed at in modern conditions. For all those purposes the electric furnace was absolutely unrivalled, and far surpassed the gas furnace. Although one might speak of a " reducing atmosphere " in a gas furnace, the atmosphere was not homogeneous; air and gas were mixing more or less gradually—indeed, if this were not so, there would be an explosion instead of a flame. Consequently, in a gas furnace there would be regions where there was oxidation and other regions where there was reduction; the whole was not under accurate control, whereas in the electric furnace control could be effected throughout. The electric furnace laboured under certain serious disadvantages; but those disadvantages had been overcome in the case of steel work, because the very high temperatures of the electric arc or the electric-resistance furnace constituted an advantage which outweighed everything else. In non-ferrous metals, however, the temperatures were as a rule very much lower, and it had proved possible to produce them more economically with gas or coke or oil. The electric furnace had therefore to effect the melting at a cost which must compare reasonably with the other kinds of melting. That, however, involved a very special design of furnace, because, after all, the cost of electricity per unit was high, and the cost of the renewal of the furnace must be low. It was in that direction that furnaces of the resistance type had hitherto failed so largely for industrial purposes; they had tended to burn out. Whether or not the furnace which had been described that evening, and which had been put forward as a tentative proposition, would get over the difficulty to the extent of becoming a commercial possibility remained to be seen after prolonged trial. Of course if an atmosphere of nitrogen, or hydrogen, or hydrocarbon gases, used in the way that Hering first proposed, could be employed so as to avoid the burning-off of the carbon resistor, the difficulty might be got over, but he had some doubts as to whether the mere coating of the carbon resistance with carborundum would overcome the trouble. Metal resistances had, of course, very limited applicability at the present time, for the same reason; they oxidized and broke down after a comparatively short life. Provided, however, the difficulties indicated could be overcome, the electric furnace offered the enormous advantage of generating heat precisely where it was wanted. If it were possible to use induction to generate the heat not outside the crucible, but within the crucible itself, that would be a further step in advance, but there were serious difficulties in the way. At the National Physical Laboratory much work was being done in connection with this question of electric furnaces suitable for use at temperatures below those for which the electric arc furnace was used, namely, temperatures ranging from 1100° C. to 1600° C.

The Laboratory had profited by the work that Dr. Hutton and others had done, and it was hoped that ultimately it would be possible to evolve a furnace which would be useful—although not perhaps economical—for the very special purposes for which an electric furnace must be used, as the desired results could not be achieved in any other way. It was his conviction that in the near future the electric furnace would be a very important factor in the metal industries, particularly in the case of the higher-grade alloys. Diverging somewhat from the strict subject of discussion, he might say that the employment of electric furnaces for annealing and the heat treatment of alloys was a factor that would also have to be reckoned with in the future. Here again would be found the advantages of control of atmosphere, and above all accurate control of temperature right through, and those advantages were worth a great deal.

Sir Gerard Muntz, Bart., Past-President, said that he would make no attempt to discuss the papers in detail, as he had not had time to give them the attention they deserved. He would like, however, to remark upon certain points that had occurred to him while listening to what had been said. Personally, he was rather afraid that some of the papers which had been read, and some of the observations which had been made, might cause those who had stood aside from science to think that, in the words of the poet, it was " better bear the ills we know than fly to those we know not of." If there were any present that evening who were of that way of thinking, he desired them to reconsider the matter, and not carry that idea away with them. Reading the papers through very quickly, it appeared to him that one author contradicted the one who had preceded him, and the unfortunate man who was trying to gather knowledge from the papers was placed at some disadvantage. If, however, the papers were, as he hoped they might be, collated and brought up to the standard which had been suggested previously, the difficulty would doubtless disappear. There were three points to which he wished to refer, one being the question of metallic losses, which had been touched upon that evening at various times, and in relation to which remarkable figures had been given. Those figures were quite inexplicable to him as a manufacturer, containing, as they did, suggested losses of metal in casting amounting to 10 per cent., 12 per cent., and even 25 per cent. In his own experience of losses in crucible castings he took an average of $1\frac{1}{4}$ per cent., which he considered high enough from every point of view. Indeed, he had known the loss to be as low as $\frac{3}{4}$ per cent. on many occasions, even when casting with the " obsolete " and " ridiculous " coke-fired furnace. He therefore thought the matter required looking into somewhat further, and that the comparison of the actual losses in the various types of furnaces which had been considered should be studied a little more closely. Another point bearing on gas furnaces which required further investigation was concerned with the absorption

of gases by the molten metal. All who were engaged in brass-casting knew that the exorbitant absorption of gases by the molten metal was one of the greatest difficulties, unless the metal was carefully protected, as was done years ago by coking up in the Birmingham process, which he did not recommend, by the use of charcoal, which he could recommend, or by the employment of a flux, which he could highly recommend. If that were not done, and done carefully, trouble would arise from the absorption of the furnace gases, with resulting spongy castings. With regard to the fluxes, it was, in the first place, necessary to know what were the fluxes now in use. There were dozens of fluxes on the market, some being natural and some being patent fluxes, the contents of which were unknown ; analysis might give a general idea of their contents, but not any definite knowledge. Some of the fluxes were efficacious and others not, but it was necessary to know of what they consisted before any opinion could be passed as to their utility. It was also necessary to know how the fluxes were applied—whether they were put in the crucible with the metal in the first instance, added during the process of melting, or used as clearing fluxes when the melting had been finished, and whether they were skimmed off or left on. All those practical points required consideration. To go back a step, to the nature of the gases which had been absorbed by brass or bronze, cupro-nickels or copper, he was prepared to be corrected by any of the scientific experts present when he asserted that the time when these gases were absorbed, namely, at what temperature, was to-day unknown ; that it was not known what gases were absorbed, nor were there any proper data for discovering exactly how they were absorbed. He believed that the discovery would be made if the matter could be properly worked out, and it would be understood how, in the case of the various metals, the various gases were given off at the various temperatures. These were points that bore on the absorption of gases in furnaces of the kind he was referring to, and he hoped that a good deal of time and attention would, before long, be devoted to the matter by scientific men. It appeared to him that in dealing with high-class bronzes and brasses, the question of temperatures was the crucial one. If the temperatures were wrong, the casting would be wrong, notwithstanding that in the first instance it might appear perfectly sound. Sometimes it happened that in a piece of brass which had been machined, no holes might be apparent, yet the microscope revealed a flaky appearance, indicating that the brass was full of tiny porosities, the metal being therefore unsound. That result, in his experience, was a consequence of incorrect temperature in casting, a matter which required to be carefully followed up. With regard to the two types of furnaces illustrated in Mr. Reason's Note by Figs. 4–6, he (Sir Gerard) had tried both forms of furnace with remarkable results. Coke consumption was considerably reduced, and, what was more, the ash output—so great a nuisance to traders in the town—was diminished by something like

60 per cent. He might remark that he had no shares in either concern, and merely offered the information as an additional hint. Referring to Dr. Rosenhain's remarks relative to the consumption of heat by the soil, the speaker would say that it was customary to put the furnaces in groups of four or five together, so that there was no loss of heat from the contact of the earth, the heat from one furnace having only 9 in. to travel before it reached that of the next furnace ; in this way the danger was avoided. The speaker agreed entirely with what Dr. Rosenhain had said in regard to the electric furnace. This furnace was the furnace of the future, but it was comparatively new, and required a lot of experience and a great deal of experimenting to bring it to perfection ; it had, however, two or three immense advantages, the foremost being, to the speaker's mind, the absolute control of the temperature. The electric furnace might be started and would work at any temperature desired ; it might be kept at that temperature with confidence that it would stay there. But with gas, oil, or coke furnaces, the best of workmen would not keep the same temperature all the way along, and in the casting of brass or bronze this uniformity of temperature was of vital importance. Another point of importance was the much greater freedom from the danger of absorption of gases in the case of the electric furnace, while the risks attendant upon dirt were removed. However expert supervisors might be, when the casters were left to themselves, they were not clean enough, and trouble arose from carelessness in this and other respects.

Mr. C. W. SPEIRS (London) said that he wished to confine his remarks to the question of the electric furnace. The material from which crucibles were made was a conductor, and the resistance could be varied within considerable limits ; it was therefore not surprising that he, the speaker, being an electrical engineer, took up the question of using the crucible itself as the heating element directly he became a crucible manufacturer. It was seventeen or eighteen years ago since he had made his first electrical crucible furnace for experimental purposes. The troubles experienced with this furnace lay in the difficulties of making contact between the mains and the crucible. It was not until 1912 that he had seriously taken up the question of electrical crucible furnaces and obtained a patent (No. 24626 of 1912). When the war broke out his firm became so busy in other directions that the matter had been temporarily dropped. He thought it worth while to make these statements, in order to let members know that such a furnace was really under serious consideration.

The speaker then described briefly the above-mentioned patent, explaining that although the diameter of the crucible varied at different heights the cross sectional area at any height, and therefore the resistance, could be altered by varying the thickness of the wall of the crucible so that the heat generated could be localized if required.

The contact difficulty was overcome by adding a ring to the crucible at the top, made in one piece with the crucible, and of such a thickness that it did not heat, and a metal terminal, water-cooled, surrounded this ring, making an excellent contact. The crucible stood on a stand of high-conductivity refractory material, also surrounded at its lower end with a water-cooled metal terminal. The point of greatest heat was between the stand and the crucible, at the bottom of the latter, where the greatest heat was required. The crucible could be placed inside a heat-insulating case, with a clay liner in it. If there were any objection to it, from his, the speaker's, point of view, it was this, that the crucible would last so long that he would not be required to supply sufficient renewals.

The PRESIDENT inquired to what size Mr. Speirs had made these crucibles.

Mr. SPEIRS stated that the size was for about 200 lb. The power taken was about 13 units for about 150 lb. of brass. In further reply to the President, the speaker stated that the voltage was about 50.

Mr. W. R. BARCLAY (Sheffield) said that the remarks he proposed to make might sound more like a list of platitudes than any contribution to the discussion. There were, however, a few things that ought to be said, and he desired to say them as well as possible. In the discussion which had taken place in the afternoon, as well as in the present discussion, there were two difficulties. The first difficulty was that of confining attention to the actual subject under discussion, *i.e.* the melting of metals. The second difficulty was that of transferring the atmosphere of the meeting-room, and of the papers, to the actual casting-shop. Anyone who had had any experience with metal-melting knew perfectly well that both advantages and disadvantages attached to each type of furnace under discussion, whether oil-fired, gas-fired, or coke-fired—leaving the electric furnace out for a moment. He wished to lay particular emphasis upon the fact that the manufacturer might be pardoned if, on taking up the papers—which the speaker regarded as valuable contributions to the discussion when taken in the proper perspective—that manufacturer felt that he was absolutely in a mist. He would suppose the manufacturer to be desirous of changing over from a coke-fired furnace to a gas-fired furnace, or from a gas-fired furnace to an oil-fired furnace, there would, in each case, be the difficulty that the figures given in the papers depended very greatly upon the human factor, making comparisons very troublesome, if not impossible. Quite recently the speaker was attached to a commercial firm in Sheffield, and he had two melting shops, both, as it happened, equipped, on the same principle, with excellently designed furnaces for coke firing. Nevertheless, he could not possibly get a uniform basis of comparison between the two shops, wholly for the reason that he had to deal with a different set of workmen in each case. It was very difficult indeed to realize all that that meant, and it served to illustrate

the point he had raised. He supposed that scarcely half a dozen of those who were present would be capable of going into a foundry and taking charge of an 80-lb. or 100-lb. crucible furnace, coking it, slagging it, and setting the pot, charging it with metal, charging it with coke, and then pouring the metal when finished. The so-called technical expert, be he manager, metallurgist, or adviser, had, of necessity, to work hand in hand with the workmen ; and if he did not, he would never get any results worth speaking of. He might perhaps get a saving in coke, but if he had some 25 per cent. of the metal rejected, of what advantage was the saving in coke ? As he had said at the outset, his observations on this point might resemble a platitude ; indeed, it was a platitude, but one of vital importance. There were two directions in which to proceed. One was to go in for whole-hearted co-operation with the workmen, letting the scientist or expert work in absolute harmony with the operatives, and endeavour to lift the latter to his level. This might be regarded as a " counsel of perfection," but more could be done in that direction than had been done. The other direction was that of attempting to eliminate altogether the human factor ; in other words, substituting mechanical devices, a good illustration of which was the tilting furnace, especially in a more perfect form than it had at present attained to. But in some way the physical element would have to be eliminated from the operation of casting, or reduced from the extent to which it was necessarily employed at the present time. The caster, whether foreman or workman, head caster or second caster, was chosen more for his muscle than his brain. If the brain could be substituted for the muscle, the speaker believed that an altogether different set of results would be obtained ; and in any discussion or review of the entire subject of metal melting this point must be taken into consideration. He was speaking from actual personal experience and knowledge, inasmuch as he had had, for the last twelve months, to work with men of all classes—as diverse, for instance, as market gardeners and schoolmasters—and try to turn them into practical metal-melters. He therefore desired to suggest, particularly to the furnace designers present, to the men who were interested in refractory materials, and to metallurgists in general, that the lines of work were those he had indicated, namely, to lift the workmen to a higher level, or, alternatively, to overcome the difficulties of mechanical operation and eliminate the question of muscle. In conclusion, Mr. Barclay desired to pay tribute to Dr. Hutton and Dr. Greenwood for their contribution. He firmly believed, with previous speakers, in the future of the electric furnace, and he was exceedingly glad that at least one contribution to the metal melting discussion had taken that particular form.

Mr. D. Clifford Highton (London) said that the papers under discussion were extremely interesting, even to one who was neither a manufacturer of furnaces nor a scientific investigator. His firm was concerned in the melting of non-ferrous metals and the selling of castings, and therefore welcomed any information leading to reduction of

costs. So far their faith had been pinned entirely to coke-fired fur-
naces. They had investigated other types, but with one result, namely,
that they were still adhering to the old coke-fired furnace. But since,
at the present time, the army seemed to have appropriated all the coke
heavers of London, and cartage was practically impossible, he would
welcome a gas furnace, which was cheap to run and at the same time
satisfactory. Personally, his works adjoining a large generating station,
he would welcome an electric furnace. On investigating the running
costs submitted to the firm by manufacturers, it had always been found
that these costs looked favourable at first sight. But inquiry into the
experience on which the figures were based brought statements that
either the experience was a laboratory one, or it was the manufacturer's
own experience, or on a particular heat of the day. Moreover, the
running costs submitted excluded certain items. Generally, therefore,
they had found the old coke figures difficult to beat. As a result of
reading the papers carefully and comparing them as far as possible in
their present form (and he ventured to express the hope that the
Secretary would reduce them to some definite standard of comparison
in regard to cost figures, with coke at say £2 a ton), he was led to the
opinion that his firm had not much to grumble at in regard to their
melting of metals. Their furnaces were natural-draught square furnaces
of the pit type. In this relation he was interested in Dr. Rosenhain's
remarks as to thermal insulation, for the reason that, although his firm
had not insulated their furnaces from the earth, they had found a
marked increase in efficiency to follow the practice of building the
furnaces closer together. They used formerly to have 14 in. or 15 in.
from the wall of one furnace to the wall of another ; the distance had
now been reduced to 9 in., allowing, of course, a greater number of
furnaces per foot run. It might be of interest to members, he believed,
if there were submitted the following figures of running costs. These
costs were not based on weighing out a certain amount of coke for a
single day's consumption, or anything of that kind, but simply on the
coke bills paid from one year's end to the other (and he was sorry to
say that a great many tons of breeze were included), and on the crucible
and wages bills. In regard to the crucibles, he might say that, during
the past year, these were not what they had been, owing to the difficulty
that manufacturers had had in getting material, most of which had
formerly come from abroad. The total costs were based on a melt of
considerably over one thousand tons, and including wages, bonuses on
output, repairing furnaces, war bonuses, and the like, worked out at
42·7s. per ton of melt.* This included practically all the non-ferrous
metals, one-third brass and two-thirds phosphor bronze, gun-metals,

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* The detailed costs were as follows :

Wages	.	.	.	.	.	.	11·7 shillings per ton melted		
Coke	.	.	.	.	.	.	21·8	,,	,,	,,
Crucible	.	.	.	.	.	.	8·8	,,	,,	,,
Furnace repairs	.	.	.	.	.	0·4	,,	,,	,,	
			Total	.	.	42·7	,,	,,	,,	

[Footnote added subsequent to discussion.—ED.]

copper, and so on. Incidentally the speaker mentioned that last year wages were up 30 per cent. and coke 75 per cent., while crucibles cost 40 per cent. more than five years ago. If the costs he had just submitted were compared with the figures given by Mr. Hocking, it would be seen that for some items his firm's costs were amazingly low, and the speaker would be glad if, in a written communication, Mr. Hocking could give information which would throw light on the subject. The speaker found that Mr. Hocking's crucibles cost, under coke, 39·8s. per ton, and when under gas 26·8s., whereas in the speaker's case the figure for last year was 8·8s. He found also that in Mr. Hocking's case a ton of coke melted 1·8 tons of metal, while in the case of his firm the corresponding figures were 2·34 tons. The life of the crucibles used by him (Mr. Highton) last year was almost 24 heats per crucible of 100-lb. size, though the crucibles were not remarkable for quality. He therefore thought, taking into consideration accidents, irregularities of workmen, and so forth, his firm should be comforted and cheered on to improve their figures next year, particularly as their furnaces, which they built themselves, had been improved in some directions.

In concluding his remarks he desired to say that he most fully confirmed the remarks of the last speaker. There was much that could be done in a general foundry, the study of which, in order to see if the ordinary furnace could be improved in any possible way, was a most fascinating subject. When an expensive machine was purchased for a machine shop, it was pretty certain that a reduced labour cost would result from the installation ; but in buying an expensive type of furnace, whether for oil or gas, there was not necessarily the same prospect of economy. He could not say whether anything was wrong with the way the problem was being tackled, but while the coke-fired furnace might not *look* efficient, there were, perhaps, reasons why it had not yet had its day.

Mr. L. C. HARVEY (London) asked whether the furnace described by Dr. Hutton, which was of quite a new design, had any decided advantage over known electric furnaces of more or less a similar character ? He referred to small electric furnaces of the " lift-out " crucible type in which resistor material was used. This furnace had a thin fireclay inner tube, forming the melting-chamber, outside which was an annular space filled with a resistor material, then another fireclay tube, then another annular space filled with insulating material, then another tube, an air insulation space, and finally an outside casing.

At the top there was a contact plate covered with the carbon granules, and at the base a similar contact plate. No water-cooled terminals were necessary.

This apparatus gave a good temperature, and was perhaps more easily made than Dr. Hutton's furnace fitted with carbon rods. One advantage of the furnace which he (Mr. Harvey) had described was that the clay tubes could be so shaped that the resistance of the resistor material could be increased over any required area so as to maintain

the highest heat zone where desired. Was not this furnace simpler than one having carbon rods covered with fireclay tubes ?

Dr. Rosenhain had pointed out the important part played by gases within a melting furnace. In electric furnaces of the type referred to, it was possible to introduce a suitable gas during the melt. Coal-gas, or any other reducing gas, could be passed through the furnace, and an absolutely reducing atmosphere maintained. With regard to the question which had been raised, of refractory linings, the writer would like to point out that the heat passing through the lining of, say, a tilting furnace was not lost. Tilting furnaces for coke fuel were usually made with a double casing, the incoming air circulating between the two casings. Practically all the heat conducted through the fire-brick lining was therefore taken into the melting-chamber again and was not wasted. Tilting furnaces were. as a rule, entirely above ground, and that being so, it was a great advantage to have the double casing and air-jacket, which kept the outside of the furnace more or less cool.

In regard to the output of brass for munition purposes, the tilting furnace had, in his opinion, to a great extent saved the situation in this country. The amount of brass melted in tilting furnaces put down since the war was very great. The output from plants of one make alone was about 4000 tons of brass per week. It would have been absolutely impossible to have obtained skilled men to operate pit-fires. In connection with the lack of skilled men, Mr. Barclay had mentioned various categories of labour, but greengrocers, costermongers, and even women could be employed on melting metal in tilting furnaces, so long as they were supervised by one good head caster. That arrangement of supervision had, of course, been adopted in many of the big munition factories.

He therefore maintained that with regard to the melting of metals, especially brass for cartridge strip, fuse rod, and extrusion billets, the use of tilting furnaces melting 6-cwt. charges, and from which the metal was poured direct into the moulds, the human factor had almost been eliminated, except in so far as correct pouring temperatures and alloying were concerned, which were the special points looked after by the head caster.

Mr. T. Teisen, B.Sc. (Birmingham), said that several of the members had spoken about electrical furnaces, and it might be of interest if he stated that at the Swedish works he had mentioned in his Note the electric furnace had also been in use for melting metal ; indeed quite different varieties of furnaces, such as coke-fired pit furnaces, oil-fired furnaces, and electric furnaces, had been tried in recent years together with the Hermansen furnace, but none of them were able to compete with this furnace.*

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* As a result of this trial, the works have now decided to build twelve new furnaces—taking altogether seventy-two crucibles—on the Hermansen system, to replace the existing furnaces. [Footnote added subsequent to discussion.—Ed.]

The electric arc furnace was suitable for steel-melting and for certain non-ferrous alloys, but not for brass, on account of the low boiling point of zinc ; and with electricity at its present price, metal-melting in electric furnaces was impracticable in this country. These furnaces could be used for copper and nickel in countries where electric energy was cheap. For melting copper about 400 kw. hours were required per ton. It had been urged in the discussion that the electric furnace possessed the advantage of being easily controlled in respect to temperature ; this was only true to a certain degree. It had to be borne in mind that it was possible to purchase that control at too high a price, regard being had to loss of electric energy by regulation and the rather high cost of the necessary regulating apparatus. It had been suggested that gas should be introduced in the electric furnaces in order to secure a reducing atmosphere, but it was clear that, in such a case, the electric furnace would be absorbing gases as much as any other kind of furnace ; therefore the course suggested should be avoided.

Dr. Rosenhain had emphasized the value of the induction furnace, owing to the greater ease with which the temperature could be regulated, and to the fact that the heat was developed in the metal itself, and the speaker entirely agreed with this opinion. The induction type was also highly economical compared with other electric furnaces.

Professor T. TURNER, M.Sc., Vice-President, referred to the wide range of matter covered by the discussion ; there was so much that speakers would like to say. The figures that had been given by Mr. Walter in relation to the consumption of gas in the Birmingham works had been adversely criticized, and it had been suggested that further particulars were required before any conclusions could be drawn on certain of the points. He would venture, however, to remind those who had spoken that the tests recorded dealt, in some cases, with over 1000 tons of metal, and that they extended over a period of twelve months. Moreover, the tests were not conducted in the presence of experts, which fact eliminated the suggestion of expert guidance ; some of the figures were results given by the works, according to their own experience, no expert from the gas committee, or from anywhere else, being present while the work was carried out. Further, when discussing the matter of the paper with Mr. Walter, the latter had said that he was rather afraid to give some of the figures, but thought it only fair to submit the results which were obtained by the ordinary run of workman in actual practice. Mr. Walter had also said that the figures given were often as much as three times as high in gas consumption as those which he could obtain himself when working in a laboratory. The speaker was glad that it had been possible to compare the coke furnace with the gas furnace, and he trusted the comparison would be carried further, since each type had its advantages. Mr. Reason had drawn attention, at a local foundrymen's association some years ago, to a simple, but important point, namely, the shape of the furnace. It was supposed

that because gas furnaces of circular section were advantageous, therefore a better result might be obtained by having a circular coke furnace. Experience, however, had shown that in coke furnaces a square section was an advantage, less coke being required, while the furnaces could be more cheaply and readily repaired. On the question of losses, Dr. Rosenhain had referred to the loss by conduction in furnaces. That loss might be an important one in some cases, particularly in laboratory experiments using furnaces on a small scale. But in the case of large furnaces—such, for instance, as the iron blast furnace, which had a very high inside temperature—careful experiments had been made on the question of heat losses, and in such furnaces the heat losses by radiation were extremely small in proportion to the total losses, while the efficiency was 75 per cent. or more. Even when the furnace was embedded in the ground and had other furnaces side by side with it, the speaker's own impression was that the heat losses would be small. Still, there was a difference of opinion, and if Dr. Rosenhain would give facts supporting his view, metallurgists would doubtless be willing to consider that aspect of the matter more attentively than hitherto. The point to which Professor Turner desired to draw attention more particularly was this, that the success of a process was always dependent upon a close examination of what was lost or thrown away. As had been suggested, a little heat might be thrown away by conduction, but in the ordinary way the greater part of the heat loss went up the chimney ; about that there was no doubt. It was essential to know the volume of the gas going up the chimney, together with the temperature and composition of the gas—whether there was excess of carbon, hydrogen, or, possibly, oxygen. Unless these three factors were known there could be no scientific control of the combustion that was being conducted. It was in that direction, therefore, that he urged attention. If it were desired to know whether fuel was being properly burnt, the gases which leave the furnace should be investigated ; that would explain almost everything. Turning to the question of metal losses, the speaker said that some members had given small metal losses, while others had indicated very high metal losses, but the difference was not really so great as might appear at first sight, the reason being that in some cases the gits, sprues, or droppings and other parts were collected carefully and added to the weight ; while in the case of the figures given by Mr. Walter, for instance, the speaker understood that the weights were those of the finished castings, the sprues and runners, &c., being put aside and disregarded. As some people might perhaps desire a very simple form of electric furnace, the speaker sketched a design which, he stated, was intended for melting a few pounds of metal at a time and gave very little trouble. Two carbons were provided, each about 3 in. in diameter, and with the current used the carbons would keep cold, and would therefore never burn out. Between the carbons was placed a small covered dish made of fire-clay mixed with about one-third of ground graphite (retort carbon), the

proportion varying a little according to the conductivity required. The vessel heated quickly, so that in less than ten minutes a few pounds of white iron could be melted in the receptacle and poured by hand. To those who desired to make a very simple electric furnace the device would be interesting, and it cost practically nothing where current was available.

Mr. A. B. Roxburgh (Newcastle-on-Tyne) desired to contribute his meed of praise for the great enjoyment he had experienced in listening to the various papers and the discussion upon them. The subject was the more interesting to him because he had been doing a great deal of work in that direction. As late as the previous day he had obtained the results from a plant which had been working with gas for the past six months, the figures given including the cost of driving the compressor. The complete costs were rather high for gas consumption, and he had discussed the matter with the proprietor of the works, who had explained that the man who supervised the work—owing to the labour difficulty, he had to be content with what assistance he could get—would, as a rule, only run one melt on Mondays ; on the other days of the week, from Tuesday to Friday, he condescended to turn up at 8 o'clock and finished at 3 o'clock. He obtained four melts per furnace per day. The actual results of the six months' working were these : the total gas consumed averaged 766 c. ft. per cwt. of metal melted, this being 70 : 30 metal for extrusion bars. He would, however, submit further experience, relating to actual working figures. These figures concerned the melting of copper for making copper castings, which were extremely difficult to manufacture in a perfectly sound condition. In this case the average result worked out rather less than 5 c. ft. of gas per pound of metal cast. At the big local munition factory there was a 12-cwt. pot for melting swarf and rather dirty sweepings. In that furnace—the first of the type which the firm had put in—the consumption worked out at 12 to 14 c. ft. of gas per lb. of metal (not of swarf) melted. On being asked by the manager his opinion of the result, the speaker's remarks were not complimentary. The fact was that the combustion space between the crucible and the wall was far too great. On the furnace being changed to one with a smaller combustion space, the working figures came out at rather over 5 c. ft. of gas per lb. of metal turned out of the furnace (not per lb. of swarf or sweepings). The figures were those for actual working conditions in the district. In a brass foundry he had visited during that week he found that eighteen months ago they had adopted gas melting for one furnace, and were just putting down two other gas-fired furnaces. The reasons which determined the putting in of these furnaces were partly connected with labour difficulties and partly the difficulty of getting coke ; but the most important reason was the advantage, under present conditions, of making castings rapidly. He was told that people would call at the works at 4 or 5 o'clock in the

afternoon and want a casting turned out promptly, if possible by 8 o'clock the next morning. The question of cost did not matter ; the only consideration was that of obliging the customer. He believed that the firm were going to change over to gas entirely. On the question of the quality of the metal and the character of the fluxes used in that particular foundry, where very dirty stuff was sometimes melted, it might interest members to know that in the course of a conversation he had with the foreman, he had inquired what flux was used, and how much for a 150-lb. pot, and, for answer, was told that a ginger-beer bottle was put in. As a fact, later a little charcoal was put on the top and was found satisfactory. Care was taken to skim the dross off the metal before casting. He did not believe that, at those works, although going in exclusively for gas working, they ever weighed the metal in, or read the gas-meter to see how much gas they were using per lb. of metal melted. Nevertheless the firm were extremely capable, and made a good profit. They were perfectly satisfied with the results of gas-firing, which paid them on account of the convenience afforded to customers and in view of the labour difficulty.

In a conversation which the speaker had had with the manager of the second largest foundry in Great Britain, he had inquired what amount of labour could be dispensed with if gas-firing were to be substituted for coke-firing. With the exception of a 600-lb. tilting furnace, the whole of the appliances were coke-fired. The speaker had requested the manager to remember all the factors in the case, such as bringing the truckloads of coke in, carrying it to the furnaces, cleaning and making the fires, clinkering them, &c. &c., and, taking account of these, the manager had stated that he could dispense with 40 or 50 men out of a total of 700 ; no inconsiderable portion of the labour costs of the foundry could thus be saved by the adoption of gas melting.

Of course they were hampered by capital invested in the coke-fired plant, but the same gentleman stated that if he made any changes, they would undoubtedly be in the direction of gas.

Mr. H. H. A. GREER (Glasgow) said that he had come to the conclusion that as the Institute of Metals had a Corrosion Committee and some other committees, there would be no harm in appointing a sub-committee to consider the important and practical work which formed the subject of the papers. He would therefore suggest that data should be collected by such a committee on a tabular basis, and that half a dozen or a dozen of the large brassfounders should be asked to make tables of the work done in the different types of furnace ; also, perhaps, a dozen of the large metal-smelters, who were merely melting up metal from swarf, scrap, &c., and putting it into ingots. It would then, at the end of twelve months, be possible to find out from the tables, which the committee would supply, what were the relative costs as between the coke-fired,

gas-fired, and oil-fired furnaces. He thought if something like that could be done, differences in estimating and difficulties in deciding what should be put in and what should not be put in would be avoided. There were many different conditions of work ; one brassfounder would run his works with a small number of crucibles, and would run them night and day, while another used plenty of crucibles in his factory, working only on day shifts ; the same results could not be expected in one case as in the other. The work with which the speaker was connected was run from 12 o'clock on Monday morning to 1 o'clock on Saturday afternoon. Oil fuel was used, and it was found that, by having a day and night shift, not only was the cost very much reduced, but the life of the furnaces was much greater, as a consequence of not cooling them down and heating them up again. These were points that should be taken into consideration. In the speaker's works there were crucible and tilting furnaces, oil-fired, and also—a thing which he had seldom seen in any place—large " air furnaces," oil-fired, for melting material which could not be put into crucibles. It was impracticable, at his works, to arrive at a basis of comparison of the cost of melting, taking for such comparison a brass foundry using, say, crucibles on Mondays, Wednesday, and Fridays. If, however, a committee were appointed to go into the matter thoroughly, and provide a table to work by, it would, he was convinced, be of great service in enabling his own and other people in the metal-refining business to improve costs. His firm would be delighted to give their figures if others were willing to afford reciprocal data.

Mr. W. J. HOCKING wished, in reply, to express on behalf of the Civil Service Department where he was situated, his gratification at the kind remarks which had been made. It was satisfactory to know that their results were considered favourable—to some extent, at any rate.

He was asked a question with regard to the kind of crucible which was used with gas as compared with that used for coke. The crucible was in shape and weight practically the same in each case, but the variation made in its composition was not known to him. This was the secret of the manufacturers, and they would not give the information away.

Reference had also been made by Mr. Smout to variations in pressure and to the regulation of those variations by means of quadrant taps. The variation in pressure mentioned in the paper was mainly such as developed in the ordinary course of melting. As the temperature rose, so there was greater pressure in the furnace itself, and this required adjustment, either with the gas or with the air taps, so as to maintain a suitable flame inside the furnace. Hence a gas-governor was hardly necessary under the circumstances contemplated. Happily, they had been so situated that they had not been subject to great variations in the supply from the local gasworks : those works had

given them a fairly constant pressure in the mains. However, it was not for him to say it could not be better.

Another question put to him had reference to the comparative lives of the crucibles under gas and coke. The life of a crucible under coke was about twelve heats, and with a gas fire about eighteen heats. The phenomenal lives of 80 and 120 which had been mentioned were obtained under different conditions from those under which they worked at the Mint. There they took the crucible from the furnace and poured out the metal, a process which occupied from four to eight minutes, according to the number of castings made ; and this shortened the life of the crucible. But taking an average year's work with gas fuel, there was an increase of about 50 per cent.

With regard to turning off the gas before shutting off the air, which was criticized by one speaker, the turning off both taps was, in actual practice, almost simultaneous, but preference was given to the gas. It was useful to show the workmen that the gas should be first, because of the danger, otherwise, of forming an explosive mixture : this was really the object of the arrangement.

Another speaker had criticized the special test in gold-melting. The Mint should, he supposed, have obtained similar results for the five years if they had carried on their melting under precisely the same conditions. This was true. In the case of the special test, they started at 7.30 one morning and went on continuously throughout the night until 1 o'clock next day. Probably if they had, in a similar manner, melted continuously until they had finished their five years' work, they would have got down to the same figures of output and cost. The test was made, not to provide some figure which should astonish the public, but to prove the capacity of the furnaces. They were in the initial stage, and it was a little doubtful whether they would be able to carry on the melting by means of gas as a fuel. Accordingly, this severe test was undertaken to ascertain whether the burners would stand the strain, and they did so. There was no mishap, and the battery of furnaces was ready for the next day's work.

One speaker referred to the difficulty of local heating with gas, and consequently, there being high temperatures at the lower parts of the furnace, that the walls of the furnace and the crucible itself were endangered. In the Mint furnaces the inlet hole was situated to one side of the axis of the pot, consequently a bias was imparted to the direction of the flame, and the pressure carried the flame in a spiral round the crucible and upwards to the flue. That preserved both the crucible and the wall of the furnace from local heating. To preserve linings they should be kept smooth. If any erosion or roughness were allowed, it quickly grew worse; and it was worth while, at the beginning of the day, to examine the furnaces, and, where necessary, patch with a suitable material.

[Other authors did not reply at the meeting, preferring to reply in writing. Their replies will be found on pp. 301–312.—Ed.]

METAL MELTING COMMUNICATIONS.

Mr. ARCHBUTT, Member of Council, wrote, with reference to Dr. Hutton's remarks in the discussion on metal melting, that he had recently made analyses of the coal-gas supplied to a number of towns and had found great variations in the calorific value and in the percentage of inert gases (nitrogen and carbon dioxide). The calorific value in many instances was below, sometimes much lower than, the low figure of 500 B.Th.U. which appeared to be coming into vogue as the standard, and the percentage of inert gases was far greater than it should be. As coal-gas could be made, and was being supplied even at the present time by some companies, with not more than about 10 per cent. of inert gases, he thought, making due allowance for the difficulties under which the gas companies were working, those inert gases should not exceed about 15 per cent. In many instances that figure was exceeded, and even 30 per cent. and more was present. To allow gas of such poor quality to be passed into the mains was neither fair to the consumer nor in the best interests of the gas undertakings themselves, and in his opinion all users of coal-gas for factory operations would find it to their advantage to make regular tests of the calorific value and analyses of the gas supplied to them. Large consumers, before installing gas-melting plant, would be well advised to have an understanding with the gas company concerned as to the maximum percentage of inert gases permissible in the gas supplied, especially where high temperatures were required, as it was obvious the highest temperatures could not be obtained with gas containing an excessive percentage of incombustible constituents.

Mr. SHIPLEY N. BRAYSHAW (Manchester) wrote that the process of metal melting by gas was still in its infancy, and consequently it was frequently carried out under the most unfavourable conditions. For example, Mr. G. B. Brook in his valuable paper stated, on p. 179, that the crucibles stood much better with gas than with coke, although he was of course using the same make of crucible in the two cases. It was only to be expected that as the use of gas became more common crucibles would be specially adapted for the new process. Mr. Hocking (p. 159) found that it was better to use a crucible made of a special mixture adapted for use with gas fuel. Users of gas furnaces had frequently complained in the first few weeks of the wastage of pots, but a few weeks later, with further experience in handling the furnace, they have given figures showing that the pots stood much better than when they were using coke.

The writer had large quantities of particulars available of the melting of various kinds of metal. The following were the details

of a continuous run on pure copper. In all cases the weights given were for the castings actually obtained, and not the amount of copper that went into the pot. The times were taken from the commencement of one heat to the commencement of the next, and this fact explained the considerable difference in the time taken. The time of heating with the gas turned on did not vary very much, the actual time (after the first 3 heats) being 30 to 36 minutes, but the interval during which the gas was off varied from 3 to 4 minutes up to 37 minutes.

The melting was done in a furnace provided with a burner similar to that used at the Royal Mint.

Full details were given in the following table :

Reference No. of Heat.	Actual Weight of Copper Cast.	Gas Consumption.		Total Time from beginning of one Heat to beginning of next Heat.
		Total.	Per Lb.	
	Lbs.	C. Ft.	C. Ft.	Minutes.
1	57¼	287	5·01	68
2	66½	186	2·80	59
3	62¼	169	2·72	56
4	61¾	152	2·46	41
5	62¾	136	2·17	39
6	62	134	2·16	40
7	62	140	2·26	41
8	62	154	2·48	72
9	62¼	139	2·23	47
10	62½	132	2·11	48
11	62½	133	2·13	46
12	62½	120	1·92	48
13	62	130	2·1	49
14	62¾	145	2·31	51
15	63	133	2·11	48
16	{ 59½ brass cast }	82	1·38	{ 24 from start to finish

The particulars given in the table above might be summarized as follows :

Total weight of copper castings in 15 heats   .   .   .   .   .   934 lb.
Total gas consumption for ditto   .   .   .   .   2290 c. ft.
Gas consumption per lb. of copper cast   .   .   .   .   .   .   2·45   ,,
    The pot was in good condition at the finish.

After the tests on copper as detailed above a melting of brass was put through, and the particulars are given in heat No. 16.

Mr. L. C. HARVEY (London) wrote that it was necessary to consider one more set of efficiency figures before making any deductions, these figures being for melting copper in tilting furnaces (600-lb. size). For copper these figures showed :

Coke   .   .   16   per cent. fuel consumption ;   15·2 per cent. furnace efficiency
Oil   .   .   12·25   ,,   ,,   ,,   11·3   ,,   ,,   ,,
Gas   .   .   450 c. ft. per 100 lb.;   13·5   ,,   ,,   ,,

It would be seen that efficiencies for furnaces of small and large capacities did not bear the same relation for the three fuels. The coke furnace was perhaps the most inefficient in small " pit fire " sizes, whereas the gas furnace was the most efficient ; when melting 70 : 30 alloyed metal in a 600-lb. size tilting furnace, the coke and gas efficiencies mentioned above were about equal. For metals having higher melting points, such as copper, the coke furnace began to hold its own against the gas furnace, but there was every reason to believe that improvement would be made on the gas consumption figure of 450 c. ft. per 100 lb. of copper. The efficiency of a coke furnace could not be much further increased, chiefly owing to loss of heat when refuelling. Oil efficiencies also were, no doubt, open to improvement in the direction of a highly heated air supply.

It must be remembered that the efficiency of a gas-fired furnace falls off more quickly than that of a coke- or oil-fired furnace. This was due to the wearing away of the surface of the furnace lining and the exterior of the crucible, with consequent increase of combustion area. Correct space for combustion was everything in a gas furnace.

He believed that this in a great measure explained the marked increase in the gas consumed after some weeks working, to which attention was drawn by another speaker at the meeting.

There was no disputing the fact that, apart from electrically heated crucible furnaces having efficiencies of 50 per cent. and upwards, gas-firing held the record for efficiency in small furnaces, and it might very possibly be cheaper to run gas- or oil-fired furnaces of larger capacities than coke furnaces when all costs were taken into consideration. Some very extraordinary results for life of gas-heated crucibles had lately been given to him. Thus, a 500-lb. crucible in a tilting furnace ran 100 heats on brass. Again, 1000-lb. size crucibles were regularly doing 90 heats and upwards on brass swarf in gas-fired " ladling out " furnaces. In another instance a crucible of 300 lb. in a gas-fired tilting furnace had lasted 197 heats, the average for some 12 consecutive crucibles being 140 heats on 60 : 40 fuse metal. Such results as these could never be expected from coke-fired furnaces.

Relative costs of working coke, oil, and gas-fired furnaces must therefore be considered in conjunction with the size of furnace to be used and the class of metal to be melted. Approximate total overall running costs for 800-lb. size titling furnaces when melting 60 : 40 brass swarf, and making allowance for fuel, linings, crucibles, labour, relining, repairs to linings, and power for blowers, bear the following relation : coke, 21 ; oil, 25 ; town gas, 37. In securing these relative figures fuel was taken at 40s. per ton, coke at 160s. per ton, oil at 2s. per 1000 c. ft. The cost of fuel per 100 lb. of metal melted worked out at 4·3d., 10·75d., and 16·0d. respectively.

He wished to apologize to Mr. Brook for criticizing his comparative costs in this manner, the more so because the table of figures in question was only, as it were, an introduction to the real subject of Mr. Brook's

paper, but he had for many years specialized in crucible furnace design and construction for all fuels, and to him it became almost a duty to see that justice was done to all of the various systems of melting metals.

Each system had its own particular merits, and every melting proposition must be considered in the light of local surroundings before a definite and accurate decision could be arrived at.

He would like briefly to refer to Mr. Brook's remarks on melting cupro-nickel. He presumed that charges had been limited to 60 lb. on account of the size of the pit fires ruling in Sheffield. When maximum output was required from natural draught coke-fired pit furnaces, it was proved in one of the large cupro-nickel melting foundries that for a 10-hour shift the 250-lb. size crucible holding 270 lb. of cupro-nickel gave this result. Four heats were run per 10-hour shift, or 2160 lb. per day and night. These crucibles lasted about 7 to 10 heats in the coke-fired furnaces, and 10 to 14 heats were now being obtained in gas-fired furnaces of the same type as that illustrated in Mr. Brook's paper.

Referring again to Mr. Walter's paper, he would offer a few remarks on the question of gas and air supply pressures. It was there stated that for high temperature work, and for melting nickel, the air and the gas should both be supplied under pressure.

This duplication of power plant seemed to be quite unnecessary, and at once removed the most attractive feature of Mr. Walter's high-pressure gas system, viz. "Simplicity of control at the furnace end."

The flame temperature when coal-gas of normal commercial value was burnt in air (both unwarmed) was about 2000° C., and any temperature up to 1650° C. in the combustion area round a crucible could be obtained with gas taken straight from the town mains, and unheated air at a maximum pressure of 1 lb. per sq. in.

Mr. F. JOHNSON, M.Sc. (Birmingham), wrote, with reference to Mr. Brook's remarks on the deleterious effects of sulphur, that the real question to be answered was, "Is sulphur in the proportions in which it occurs in commercial brass melted in coke-fired furnaces really deleterious?" He (Mr. Johnson) considered that the answer was in the negative. If that were not so, all brass melted in coke-fired furnaces must be of inferior quality.

The author's analyses showed such very small percentages of sulphur that they might have been introduced with the copper, even if the latter had been electrolytic. He (Mr. Johnson) had shown, both by analysis and by the aid of the microscope, the presence of sulphur in electrolytic copper. Moreover, Sperry had shown that with five times the amount of sulphur given by the author in brass melted in the coke-fired furnaces, the working and mechanical properties of 60 : 40 brass were not impaired

The question of the temperature of the molten metal raised by Messrs. Thornton and Hartley was one of very great importance. The points to consider were :

1. Time required for skimming.

2. Time required for pouring, especially where a large number of moulds had to be filled and it was necessary for all of them to be poured sufficiently hot.

It would rarely happen in a foundry making small castings that much time could be allowed for the metal to cool.

3. Pouring at a sufficiently high temperature to allow of thorough feeding from gate or riser.

4. Pouring at a sufficiently high temperature to allow of the escape of gases, either occluded or generated in the mould.

He thought that one could more easily err in practice in pouring brass too cold than too hot.

With regard to the use of flux, he had found salt of questionable value. It produced noxious, choking fumes, and appeared to produce little improvement.

There were several points in Mr. Walter's paper to which he would like to refer.

On p. 196 he would suggest a fourth source of loss, not included in Mr. Walter's list, viz. the absorption of metal by the walls of the crucible. The amount of metal lost in this way might not be very large, but it was appreciable, and he had himself seen old crucibles containing numerous small " shots " of metal in addition to the metal absorbed in the forms of oxide or silicate.

With regard to the duration of the first " heat " when using high-pressure gas, he (Mr. Johnson) had been unable to find in practice anyone who could claim so short a period as that claimed by the author. In the case of one Birmingham firm using high-pressure gas, the duration of the first heat was nearer three hours than two.

There was an omission from Table IX. to which he would draw the author's attention, viz. the value of recoverable metal in ashes from solid fuel-fired furnaces. This value should not be ignored when making a comparison of the two methods.

He would like to ask the author whether he had calculated his percentage losses (p. 197) on remelted metal, or on alloys made from virgin metals ? The percentage loss in the latter case would, of course, other conditions being equal, be greater.

Although he (Mr. Johnson) was personally in favour of the use of gas, he considered that a satisfactory case had not yet been made out for high-pressure gas. He thought it was to be regretted that the authors of papers had so completely overlooked the disadvantages of their own systems. They should look these disadvantages squarely in the face—he spoke of such things as the deafening noise in a foundry when using high-pressure gas, a noise which was so great as to necessitate shouting in order to make oneself heard, the readiness with which

gas could go to waste, and the difficulty of overcoming the prejudices of workmen. These things, if serious disadvantages, ought not to be insuperable difficulties, but they would be only overcome by their clear recognition by those who had the future welfare of gas-melting at heart.

From his own experience, he was in hearty agreement with those speakers at the meeting who preferred to use gas at ordinary pressure aided by air under pressure. He had seen furnaces working under this system, which for speed of melting would be hard to beat, and which worked far less noisily than the high-pressure gas furnace.

In expressing his appreciation of the paper by Dr. Hering, the importance of which from an educational standpoint was not to be gauged in ratio to its size, he would refer to the author's statement on p. 247, that lack of fluidity, owing to the metal being too cold, would give rise to bad castings. From recent experience he (Mr. Johnson) would suggest that other disadvantages accrued from this condition—viz. premature shrinkage, causing cavities in castings, and occlusion of gases, causing porosity. In both these cases rapidity of solidification was bad, and the remedy was to superheat the metal in order to allow of correct feeding and the escape of gases. So long as superheating was not synonymous with *over*-heating, the remedy was justifiable, even with brass.

He noted with interest Dr. Hering's recommendation (p. 249) to heat from the bottom, so that the volatilized zinc would condense in the upper layer. It was necessary, however, not to lose sight of the fact that that upper layer should be below the boiling point of zinc, in order that the volatilization should be appreciably minimized. To keep molten brass, even of the high-zinc mixtures, at a temperature lower than the boiling point of zinc, would not be practicable in the foundry. It seemed, moreover, questionable whether a serious disadvantage might not accrue from having a charge of molten metal varying appreciably in temperature, in spite of the fact that, in pouring a large number of moulds, the hottest portion of the charge would be poured last. A point in favour of heating from the bottom was that the lower layers, in addition to being protected by the superjacent cooler layers, were also under pressure of those layers, and would therefore be subject to a slower rate of volatilization, resulting from the raising of the boiling point.

He (Mr. Johnson) was in complete agreement with the author regarding the cause of deterioration in remelted metal. In the case of brass, the quality should suffer, and, in his experience, did suffer little if any deterioration in remelting, if sufficient care were taken to remove suspended oxides.

The oxides of aluminium and manganese, however, were particularly difficult to eliminate

M. HENRY LE CHATELIER (Paris) wrote that many of the conclusions arrived at during the Metal Melting Discussion, as a result of industrial experiments, agreed very well with results previously obtained in the laboratory. The first experiments on gas melting at a high temperature were made fifty years ago by M. Schloesing, at that time Director of the State School of Applied Science, who still, in spite of his ninety years, took a very active part in the work of the Academy of Sciences.

A kilo. of iron was cast in one hour with a type of blowpipe which, from that time, was greatly in use in the laboratories of France. He made on this occasion experiments on the use of magnesia, which experiments became the starting-point of the industry of magnesian refractory products.

Since then the writer had often employed the same method of heating, of which the essential principles were enumerated below.

1. To obtain very high temperatures the gas and the air should be intimately mixed, so as to give a very short flame. In spite of the high velocity with which the gaseous mixture entered, combustion took place at a distance of only a few millimetres in a preheated furnace. In this way the maximum concentration of heat was obtained. With a non-homogeneous mixture the combustion was only progressive, and did not attain its maximum in many cases till after the flame had left the furnace. A perfect mixture was obtained immediately by circulating the gas in a pipe having a length fifty times the diameter of the nozzle. Other means of mixing could certainly be contrived; but the one given had the advantage of great simplicity.

2. The velocity of the gas should be such as to prevent the flame firing back, in spite of the heating by radiation and the conductivity of the iron pipe through which the combustible mixture entered. A velocity of 50 m. a second might be used, which corresponded to a pressure gauge of 125 mm. of water. This velocity could be given in full only when the furnace was already somewhat heated, without which the flame was very long. The diameter of the nozzle through which the gas entered was calculated according to the consumption of gas required. The speed should never be allowed to fall below half, *i.e.* below 25 m. per second, otherwise there is danger of the gas back-firing in the entrance pipes, resulting in their immediate fusion.

3. The space open to the flame round the crucible should be small. There was no purpose served by the retention of the flame in the furnace, as combustion and exchange of temperature were practically instantaneous. The exchange of temperature was principally due to convection, which increased proportionately to the speed of the gas, owing to the parallel development of eddies in the gaseous mass. A suitable size for the annular space round the crucible was a tenth of the external diameter of the top of the crucible, say, 5 mm. for a small laboratory crucible of 50 mm. diameter.

4. The diameter of the nozzle which determines the supply of gas should vary with the final temperature or the speed of melting desired. To obtain the temperature of 1600° necessary for the melting of soft iron, the diameter of the mouth of the nozzle should be equal to $\frac{1}{5}$ of the diameter of the top of the crucible, *i.e.* 10 mm. for a crucible of 50 mm. diameter. These dimensions corresponded to the 50 m. speed of the gaseous mixture recommended above. If an attempt were made to reduce the speed the section of the nozzle must be doubled.

5. The most rational method of introducing the gaseous mixture
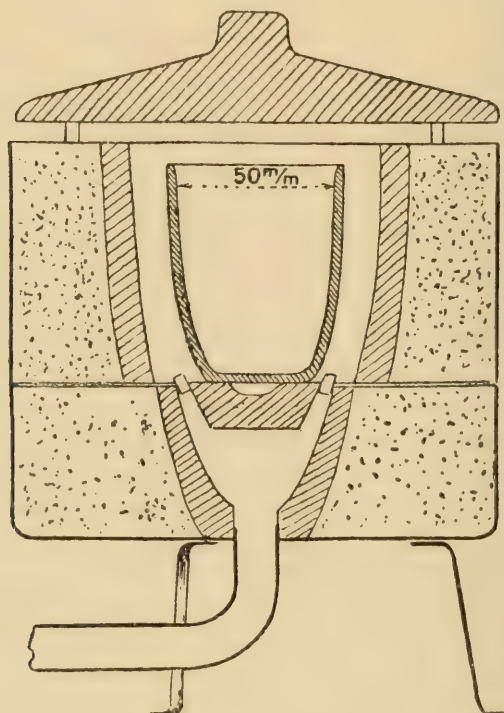
Fig. 1.

into the furnace was that suggested by M. Schloesing. He made the mixture enter the furnace through an annular orifice surrounding the base of the crucible. For a 50 mm. crucible this annular space should have an interior diameter of 30 mm. and an opening of 1 mm., it being understood that the base of the crucible should be a little less than 30 mm. in diameter. In this way symmetrical heating was obtained, resulting in concentration of heat and lengthening of the life of the crucibles. A furnace similar to the one described could be easily constructed in the laboratory with pieces of broken crucibles, as shown in Fig. 1. The shaded parts represented sections of the crucibles and crucible cover, the dotted parts refractory lagging—say, for example, a mixture of 1 part clay with 2 parts of old crucibles ground up. The

openings of the passages necessary for the entrance and exit of the gas from the furnace were assured and regulated to the required dimensions by small wedges placed in the annular slit.

This arrangement for the entrance of the flame from below would be inconvenient for industrial use, because the annular nozzle would be rapidly blocked up through material falling in. The gas was therefore made to enter through lateral orifices, by preference tangentially to the crucible, so as to assure a better distribution of temperature. With the same object it was an advantage to have two symmetrical gas entrances opening at opposite sides of the circular furnace.

6. To obtain the speed necessary to prevent the back-firing of the flame there was required a previous compression of either the air or the gas, or of both. Practically, it ought to be possible to arrange
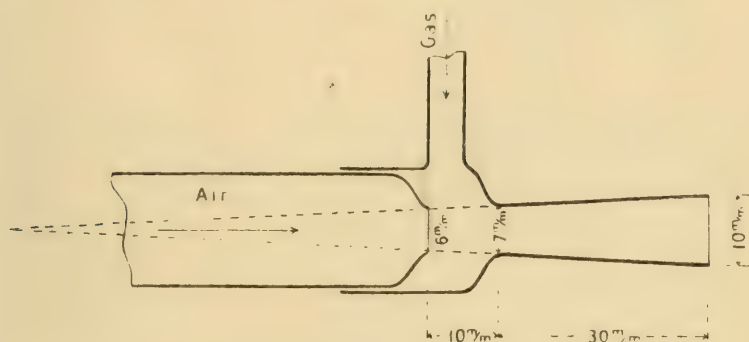
FIG. 2.

for the air only to be under pressure, and to draw in the combustible gas by means of the air by projecting it in the injector principle.

This allowed of a considerable fall of pressure behind the narrow opening through which the gas entered and *vice versâ*. A considerable compression was necessary at the front of the opening to assure the circulation of the gaseous mixture in spite of the resistances which it encountered on its way.

There were two different methods of compressing the air : for a low compression—use, for example, one-tenth of an atmosphere, a fan, and compress the total quantity of air required for the combustion ; for a pressure of several atmospheres special compressors were required, such as were already in use in many factories. In this case the excess of pressure was utilized to draw in the combustible gas and also the air taken in from the atmosphere, in such a way that the initial compression did not need to carry more than a fraction of the air necessary for the combustion.

For securing pressures of one-tenth of an atmosphere the injector shown in Fig. 2 was used, the dimensions of the injector being calculated to serve a nozzle of 10 mm. diameter. The 50 cm. tube which was necessary for the mixture of the gas, and was inserted

between the injector and the nozzle, was not indicated on the sketch. This arrangement served to heat a 50 mm. crucible up to 1400° C. For larger crucibles it was necessary to increase the dimensions of the injector proportionately to the dimensions of the crucible.

With a pressure of 1 atmosphere the injector shown in Fig. 3 was employed. The pipes admitting the gas and air at atmospheric pressure of course had taps or regulating valves.

7. The calorific efficiency of these furnaces could be considerably augmented, especially for obtaining high temperatures, by heating the gaseous mixture before it passed into the furnace. The temperature could in this way be raised to 300° without fear of premature ignition.
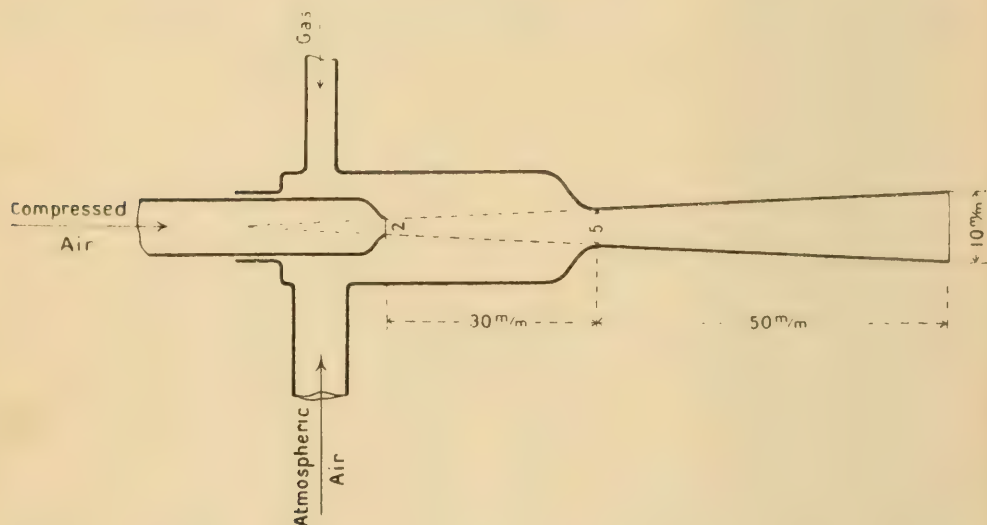
FIG. 3.

This theoretically allowed of the raising of the temperature of combustion by 200°, *i.e.* a temperature of 1800° could be obtained, sufficient for the melting of platinum.

In the laboratory this preheating of the gaseous mixture could be carried out by causing it to circulate in a long iron tube heated over a simple laboratory combustion furnace. Industrially, some means of heating could be employed which utilized the heat, now lost, from the furnace. However, there was always danger of accidentally overheating some part of the metal apparatus sufficiently to cause ignition of the gaseous mixture, resulting in either small explosions or, worse, the melting up of the metal apparatus through which the gas circulated.

It was safer in such a case to use an indirect means of heating by passing the gases from the furnace under a steam boiler and heating with the steam, thus producing a regenerator through which the gas should pass. With a boiler pressure of 10 atmospheres it should be possible to raise the heat of the gaseous mixture to 150°.

His (Professor Le Chatelier's) experience having been with small laboratory furnaces, it would be necessary to proceed carefully in applying the results to industrial practice.

In the foregoing it was assumed that the quantity of heat necessary for the heating of a crucible depended on the one hand upon the cube of the crucible—*i.e.* the third power of the linear dimensions—and, on the other hand, on the external surface of the furnace—*i.e.* the square of the linear dimensions, and the inverse of the thickness of the walls. If it were admitted that all dimensions changed proportionally, the losses by external radiation were only, in the end, proportional to the primary power of the linear dimensions. A consumption of heat had thus been allowed for intermediate between the cube and the first power, *i.e.* varying with the square of the linear dimensions. Thus it was necessary to vary the dimensions of the burner proportionately to those of the furnace and the crucible.

Mr. A. J. G. SMOUT (Birmingham) wrote that Mr. Reason's championing of the much-abused coke-fired furnace appeared not to have met with the attention in the discussion on metal melting that it deserved. Mr. Reason brought to the notice of the meeting improvements in the coke-fired furnace which would delay the coming of its rivals gas and oil in many foundries, for the improved furnace bottoms that he described in his Note would undoubtedly increase the efficiency of the coke-fired furnace. It would be of interest and value to any who were studying the subject of metal melting if Mr. Reason could give some data showing (*a*) the coke consumption per lb. of metal melted on the old-type coke furnaces and on the furnaces fitted with the patent bottoms, and (*b*) the crucible life in both cases. Also, if he could state the approximate life that one might reasonably expect to get from these bottoms.

Mr. H. JAMES YATES (Birmingham) wrote that, had time permitted at the meeting, he would have wished to congratulate Mr. Hocking upon having put forward so important a contribution to the subject ; its importance was all the greater because of the fact that the figures for gas were obtained for a quantity of coinage metals approximately 10,000 tons.

On p. 163 a summary was given of the consumption of fuel per ton of metal melted over the whole of the period 1911–16. That worked out at an overall figure of 5·45 c. ft. of gas per lb. He was of the opinion that this figure was rather on the high side, and he attributed this to the fact that, as far as he could gather from the paper, no preheating of the metal took place. In commercial practice he had found that to get good results preheating of the metal was a very necessary part of the process. It must not be overlooked, however,

that in this figure of 5·45 was included the melting of a cupro-nickel alloy, which took a large quantity of gas.

Mr. Walter's figures also were not such as to do full justice to the case for gas, because although his figures were confirmed by the speaker's experience with high-pressure gas, yet if such figures had been really representative of the best that could be done by gas, the case for that fuel would be far from the present excellent one.

Mr. Brook, however, had established a very good case for gas in the melting of metal, but as regards other two of the papers, it was unfortunate that the one should have dealt with high-pressure gas, in which the consumptions are known to be high, and that in the case of the other the authors were merely experimenting. What the melting industry required was definite practical results which would inspire them with confidence in adopting gas furnaces : such practical results were available and were of a highly satisfactory nature, and had those authors been in a position to quote such figures, it would have been a distinct advantage to the cause of gas melting. The preheating of the metal was an invariable part of his own practice, as he had already indicated, and was an essential factor in fuel economy. He observed that Messrs. Thornton and Hartley referred also to pre-heating of the gas and air. This was naturally the first expedient anyone would think of in the direction of fuel economy ; and indeed the advantages of the regenerative principle were so well known that what had to be considered in each case was, not the merits of re-generative methods themselves, but whether in the particular case these methods could be applied consistently with economical adaptation to foundry conditions, sufficiently moderate first cost and cost of upkeep. In many instances it did not by any means follow that these conditions could be assured. For his own part, he had found the preheating of the metal only very satisfactory as regards economy in gas consumption and other respects. The very low figure of 1·49 c. ft. per lb. of brass melted represented work done without pre-heating the gas or the air, and the results indicated by that figure were very remarkable, both for this reason and for the fact that they were results arrived at on an ordinary satisfactory basis and not under special test conditions. While 1·49 was the best of the results so ascertained, the average results of a number of days ordinary working were as low as 2 2 c. ft. per lb.

AUTHORS' REPLIES TO METAL MELTING
DISCUSSION.

Mr BROOK, replying to the discussion at the meeting, wrote that he would like to tender to the members his thanks for their reception of his paper, and for the several points of interest and criticism raised. He wished, at the outset, to make a special point which seemed to have a general bearing on all the papers contributed on melting. For purposes of comparison, it would seem to be essential either that the same alloy be used for different types of melting, or the exact composition of the alloy used in any test should be stated ; also the exact temperature of any alloy should be definitely stated and adhered to throughout the test. Obviously, a temperature variation of 50° to 100° C. for any particular alloy would render the comparison between the different types of furnaces valueless. For any individual author's test it would alter or even negative the usefulness of published results. In the test carried out by him (Mr. Brook) both these conditions were fulfilled, namely, the constant composition of 80 per cent. copper and 20 per cent. nickel, and the uniform casting temperature of 1370° C. The weakness of any other basis of comparison would be obvious when it was pointed out how loosely the word " melt " was used. For example, in Mr. H. James Yates' criticism of Mr. Walter's paper, he spoke of " the average gas consumption of 9·4 c. ft. per lb. of cupronickel *melted*. . . ." When it was remembered that the melting point of cupro-nickel of this composition was about 1180° C., and that it had been found essential in practice to cast at a temperature of 190° higher, obviously a very great difference would be found between the gas required to *melt* it and the amount necessary to attain a temperature of 1370°.

He (Mr. Brook) recognized that the size of furnace available for the test was somewhat on the small side, and hence that the fuel figures would be proportionately high, but he desired to point out that the majority of Sheffield manufacturers at that time found by experience that the best quality of metal was ensured by the use of crucibles of 70-lb. capacity in coke-fired furnaces. Thus the criticisms offered by several speakers as to the test being done on too small a scale were not tenable. He pointed out that his main object was, apart from the quality of the metal produced, to test the relative costs of gas *versus* coke under as nearly as possible uniform conditions, both in size of ingot and commercial practice.

In reply to Mr. Harvey, he would point out that his criticisms of the table on p. 173 were irrelevant, as the author definitely stated that he recognized the limitations of the above test, and such limitations prompted the more extensive test which formed the basis of the paper

under discussion.   In the preliminary test referred to by Mr. Harvey, it was not claimed that such was anything but a laboratory experiment. Mr. Harvey was wrong in stating the size of the furnaces used—the gas furnace was arranged for a maximum-sized crucible of 70 lb., and the oil furnace for 80 lb., and the coke furnace for 60-lb. crucibles respectively.   It was the employment of such furnaces for smaller amounts that prompted the author to use the words quoted above on p. 173 of the paper.

Dr. Rosenhain pointed out that one should take into consideration the cost of converting the fuel into gas.   On this head he (Mr. Brook) would say that the value of the by-products from such fuel should also be taken into consideration, and his results would seem to prove convincingly that gas, at the current rate in Sheffield, was more economical for the melting of a standard alloy under standard conditions than coke.   With reference to the attainment in a gas furnace of a temperature considerably over 1600° C. mentioned by Dr. Rosenhain, the author would like further information, as from experiments carried out it was very difficult to raise the temperature of the *contents* of the crucible (cupro-nickel) higher than 1400°.

In reply to Mr. Reason, who criticized the use of the word " expert," surely if a test were to give the best results from any three furnaces side by side, one would naturally have the services of men trained to each particular type of furnace, rather than one who had little knowledge of such furnace, if comparable and reliable results were to be obtained.   Mr. Reason, in speaking of coke at 16s. per ton, was obviously under a misapprehension as to the type of coke.   Hard " steel " or " metallurgical " coke was necessary for the attainment of the high temperature required for cupro-nickel.   Its present price was 42s. per ton !   He was also under a misapprehension in reference to costs, as the writer's experiments were carried out with gas at normal pressure and not at high pressure.   As pointed out in reply to a previous speaker, his (Mr. Brook's) tests were carried out in crucibles that were fairly comparable with those used in local practice, and which were found to be best.

With reference to the two furnace bottoms for coke-fired furnaces that were exhibited at the meeting, he desired to add that the trial of one of these types was not successful, as the high temperature attained melted away the firebars or the frame supporting them when used in furnaces for the production of cupro-nickel.

Mr. Brook, replying to the written discussion, wrote in answer to Mr. Johnson's remarks on the effect of sulphur, that reference in his paper was made not to the effect of sulphur on brass, but to the effect of that element on cupro-nickel, in which it was very deleterious.

Dr. HERING, in reply to the discussion on his paper, wrote that he appreciated Mr. Johnson's remarks, and desired to say that the metal must, of course, be hot enough to avoid porosity and premature

shrinkage. The author's remarks about excessive superheating referred to those unnecessary losses of heat which could easily be avoided by reducing the time between the generation of the heat and getting the metal into the mould.

In heating from the bottom, the hottest metal would not long remain at the bottom, as heated liquids always rise ; water below 4° C. is a rare (though fortunate) exception. The bottom was always poured last, hence it would be even desirable to have it slightly hotter.

The volatilization of zinc from zinc alloys, at temperatures which were absolutely necessary, was an unavoidable loss which could be reduced only by the reduction of time, *i.e.* by quick heating and pouring. Another way was by heating under pressure, which presumably was not practicable on a large scale, though it was being done on a small scale in making pressure castings.

The troublesome oxides of aluminium and manganese seemed to come to the top readily in a particular type of electric furnace in which there was a strong, forced upward circulation, judging from tons of very impure remelted brass which came out as fine clean metal.

Mr. Hocking, in further reply to the discussion at the meeting, wrote that in Mint practice the rate of loss in melting was ascertained at the close of each day's work. This form of supervision was obviously necessary, and was particularly important in the case of the precious metals. The time and labour involved in recovering metal reduced the number of heats obtained daily from the furnaces. The residual heat after the last round, which in most foundries would be available towards another pouring, was unused, and its effect in reducing the mean cost of fuel per unit of output was lost. No reliable data existed for estimating the extent to which the Mint returns were affected by this embargo, but, as the number of rounds daily in the large melting house varied from three to four, the effect of this loss must be considerable, and the consumption of gas relative to the outturn must be regarded as appreciably higher on this account than it would be under ordinary factory conditions.

This statement of their practice, coupled with the remarks made at the meeting, should meet Mr. Hartley's criticism of the divergence between the results of the special test of gold melting as compared with those for five years. During the latter period the number of melts per furnace varied between five and six daily, so that each furnace would be heated from the cold five times as against once during the special run. In addition to such losses, there would be those due to closing the account five times as against once. Therefore the alleged " wastage " of fuel at the rate of 70 per cent. arose mainly from the methods inseparable from Mint work, and would occur with coke as well as gas.

In further reply to Mr. Brayshaw, the mean calorific power of the gas used in the Mint, as found in an official test made in September 1915, was 526·8 B.Th. units gross per c. ft.

The returns relating to melting with coke were subject to the same rate of increase as those for gas, and the two sets of figures were therefore strictly comparative.

The staff employed was practically identical throughout the two periods of melting reviewed.

Mr. Highton asked for an explanation of the fact that the costs of melting with coke at his firm were at a lower rate than those at the Mint. From the footnote added subsequently to the discussion it appeared that, setting aside wages, the rate for fuel per ton melted was practically identical (21·4s. and 21·8s. respectively), and that the great difference was between the costs of crucibles. This item, therefore, was the only one that required consideration. At the Mint all graphite goods were included under the head of crucibles. On account of the risk of loss with precious metals, pots were thrown out earlier than otherwise they would be. Most of the Mint melting being at high temperatures, the consumption of graphite materials was proportionately greater. The average cost for crucibles given by Mr. Highton was a very low figure. He stated that the 100-lb. crucibles gave about 24 heats each, that was a total melt of about 1 ton each, while the cost for crucibles per ton melted was shown to be 8·8s. Each crucible therefore seemed to have cost 8·8s., which seemed a low price, while the costs of the cover, muffle, and stand were neglected, if these accessories were used at all.

Mr. Highton compared the amounts of metal melted per ton of coke. The larger amount melted by his firm would naturally arise from the low temperatures required by brasses, phosphor bronze, &c., which were the classes of metal cast. The various metals cast at the Mint were recorded in detail in the paper.

Drs. HUTTON and GREENWOOD, in reply to the discussion at the meeting, wrote that the evidence of interest in electrical melting, indicated by the remarks of Dr. Rosenhain, Mr. C. W. Speirs, and Mr. L. C. Harvey, was encouraging. As regards a comparison of the electric furnace described by the writers with other forms, it should be pointed out that their object in communicating the present paper was rather to excite interest in the problem than to postulate a final form of furnace

Mr. REASON, replying to the written discussion, wrote that Mr. A. J. G. Smout was under a misapprehension in describing his Note as championing coke-fired furnaces ; the Note was written by request, as any account of melting non-ferrous metals would be incomplete without reference to the coke-fired furnaces.

In reply to question (A), the coke consumption given in Table II. was based upon well-constructed furnaces in good repair ; the improved bottoms would effect economy in coke consumption, cost of linings, and crucibles.

(B.) The life of any furnace bottom depended upon the condition of the furnace lining. If allowed to burn away, so that the coke was carried on the bottom instead of the firebars, the life of the bottom would be considerably reduced ; with proper care furnace bottoms should last twelve months, firebars six months.

Mr. Teisen, in further reply to the discussion at the meeting, wrote that all the papers had been very interesting to study, especially those which dealt with the town gas-fired furnaces *v.* the old pit furnaces. Some of the papers, in his opinion, referred too much to particular cases, with the result that the readers lost the general view.

The chief result, in his opinion, was that on one side they saw the old coke-fired pit furnace, which showed a higher loss of metal but a more moderate melting cost, and on the other the town gas-fired furnace in which the fuel cost was proportionally higher, while the loss of metal was smaller.

The Hermansen furnace, about which he had spoken, combined the advantages of both systems, and, at the same time, superseded them, as both the fuel cost and loss of metal were less than in any of these furnaces.

He would be glad at a later date to go more fully into this question, but for the present he had worked out a comparison of melting costs of this furnace and other furnaces, and the result was given below. The figures given for all the furnaces were figures obtained by actual working in large works, and they could easily be adjusted as the case might require.

These figures might help to give an insight into the two main factors of the melting costs of the different furnaces, and he would be glad to give to all members interested any other information wanted.

Comparison of Melting Costs of Hermansen Furnace, Coke-fired Pit Furnaces, Town Gas-fired Furnaces, and Coke-fired Tilting Furnaces.

The following table showed how the several types of furnaces compared in the matter of fuel consumption and loss of metal, reckoned in percentages of the weight of metal melted :

	Fuel Consumption.	Loss of Metal.
Coke-fired pit furnace . . .	40 per cent.	$1\frac{1}{2}$ per cent.
Town gas-fired furnace . . .	4 c. ft./ lb.	$\frac{3}{4}$,,
Coke-fired tilting furnace . . .	15 per cent.	$1\frac{1}{2}$,,
Hermansen furnace	18 ,,	$\frac{1}{2}$,,

Taking the fuel and metal costs as :

Coal . . . . . . 24s. per ton
Coke . . . . . . 30s.   ,,
Town gas . . . . . 1s. 10d. per 1000 c. ft.
Metal . . . . . . £93 per ton, or 10d. per lb.

the following melting cost per ton of melted metal were obtained :

	Fuel Cost.	Loss of Metal.	Total.
Coke-fired pit furnace . .	12s.	28s.	40s.
Town gas-fired furnace . .	16s. 6d.	14s.	30s. 6d.
Coke-fired tilting furnace . .	4s. 6d.	28s.	32s. 6d.
Hermansen furnace . . .	4s. 4d.	9s. 4d.	13s. 8d.

Messrs. THORNTON and HARTLEY, in further reply to the discussion at the meeting, wrote that, with regard to the remarks of Sir Thomas Rose, fluxes were claimed to lessen the contamination of the metal melted.   In their own experience with coal-gas fuel they had not found any very decided advantages in this direction, although it appeared probable, as mentioned by Sir Gerard Muntz, that they played an important rôle in preventing the absorption of gases by molten metals. Salt was claimed to be efficacious, especially in preventing the absorption of sulphur by copper alloys, an advantage which was of little importance with coal-gas as a fuel.   The authors had made series of melts of copper both with and without a covering of salt, but had not been able to find any advantage in this connection resulting from the flux, the absorption of sulphur during a melt, if it occurred at all, being very small ; further, common salt was an extremely unpleasant flux with which to work.   For themselves, the authors had been in the habit of using about 2 to 4 oz. of borax in conjunction with charcoal, added as soon as the ingots were broken up, as the flux materially reduced the weight of skimmings.   In casting in moulds of the type referred to by Sir T. K. Rose, they found a certain amount of the flux in the top of the casting, as they had not been able to remove completely, prior to pouring, the small quantity of flux which collected on the surface of the metal at the point of contact with the side of the pot.   In sand-casting they had found no trouble at all with fluxes.

With regard to the remarks of Dr. R. S. Hutton, the authors were in agreement with the suggestion made by this speaker concerning the necessity for a simple device for measuring the gas and air supplied to the furnace, or at least an adequate governor to ensure the maintenance of constant proportion of gas and air ; they had done a certain amount of work in this connection which they hoped would enable them to construct a suitable piece of apparatus.   The authors felt that the greatest weakness of existing gas-fired furnaces was their liability to waste fuel when carelessly used, and during the discussion itself one of the authors

raised this point in connection with some of the results which were published. In certain cases good results were obtainable by observation of the flame produced, but this was not always the case.

The gas pressure for the furnace used by the authors was 25/10ths water-gauge, whilst the air pressure varied from $1\frac{1}{2}$ to 2 lb. per sq. in., according to the metal melted.

With regard to the comments of Mr. H. James Yates on the brass figures, the authors noted that he considered the consumption for the initial melt as high, and the figure for the final melt as low. With efficient preheating the authors found no difficulty in pouring brass at 1000° C. with a consumption per lb. of 1·6 c. ft. of gas of the quality referred to, once the furnace had become warmed up ; and in that case Mr. Yates would find it was not a very difficult matter to reduce the final melt to the figure given. The authors welcomed Mr. Yates' further remarks, which, coming as they did from a competitive manufacturer, served to emphasize the fact that in many cases in ordinary commercial practice gas furnaces were inefficiently handled.

In reply to Mr. L. C. Harvey's remarks relating to a reducing atmosphere in a gas furnace, the authors thought that it was very doubtful whether reducing conditions existed in the crucible chamber of a blast-furnace in many cases as, although the combustion might not be complete in that portion of the furnace, nevertheless, to make the appliance work at all, it was necessary to introduce a considerable amount of air with the gas, and to have a high partial pressure of carbon dioxide and steam which, under the working conditions, often produced an oxidizing atmosphere. Spelter was oxidized in brass melting and the crucibles lost graphite. The conditions determining whether the atmosphere was oxidizing or reducing, would of course depend upon the metal under consideration as well as the temperature inside the furnace. The authors had hoped that more would have been said in the discussion concerning pot life. In a gas-fired furnace of the existing types it was, of course, impossible to prevent the loss of graphite ; this was emphasized by the following data given by Rhead and Wheeler, showing the equilibrium composition of carbon monoxide and carbon dioxide mixtures in presence of carbon. From these it was to be concluded that in coke-fired furnaces, when little loss of graphite from the pot took place, the fuel was only burnt to carbon monoxide in the most effective portion of the furnace.

Temperature. °C.	Per Cent. CO_2.	Per Cent. CO.
850	6·23	93·77
950	1·32	98·68
1050	0·37	99·63
1200	0·06	99·94

With regard to Dr. Rosenhain's remarks in connection with the question of preheating, this, of course, should be done mainly by the waste heat of the furnace gases. On the other hand, Dr. Rosenhain

was in error in stating that no good result was obtained by providing an air-jacket round the furnace chamber. Obviously, if the air supply to the furnace was first led round the outside walls and then, say, through the waste gas flues, and finally into the combustion chamber, the air-jacket would serve to lessen the conduction losses, which were ultimately determined by the temperature of the outside walls of the furnace.

With regard to the question of conductivity, the authors inclined to the view that Dr. Rosenhain had over-emphasized its importance : they had hoped to be in a position to refer to this matter more fully in this reply, but unfortunately were unable to assemble the data in time. The authors would, however, cite one experiment in which a furnace built of brickwork, the conductivity of which they had found previously to be 0·003, was then provided with a lining 1 in. thick of a diatomite material, the conductivity of which was approximately 0·0005, but without any noticeable saving. The authors did not mean that there was no saving, but that the saving was so small that it would be nullified by any small error in the adjustment of the relative gas and air supplies.

In reply to Mr. A. J. G. Smout, with regard to the gas consumption per lb. of metal melted for a 150-lb. size of furnace, these were generally better, if anything, than those obtainable with the 70-lb. size to which the authors referred. A consumption of from 4 to $4\frac{1}{2}$ c. ft. of gas per lb. of brass melted, such as mentioned by Mr. Smout, appeared to indicate inefficient preheating, assuming that the gas and air supplies were properly adjusted.

Concerning pot life, Mr. Smout stated that the figures given by the authors were misleading, as they referred only to one size. If Mr. Smout would refer to the context he would find that the authors were careful to specify that their statement of pot life referred to the 70-lb. size of furnace. Concerning the pot life quoted, these results were obtained during four months' working of this furnace in connection with a pattern shop foundry. The metal was for the most part cast in chills, but little being sand-cast.

With regard to the figures cited by Sir Gerard Muntz for spelter losses in brass melting, these figures were much the same as those quoted by the authors as their own experience. The authors mentioned McWilliam and Longmuir's figures and those quoted by Gillet in the hope of hearing an explanation of those abnormally high losses. They were pleased to find that their conclusion with regard to the suitability of charcoal plus flux in brass-melting supported Sir Gerard's experience.

Not only the question of the absorption of gas, but also the conditions under which the absorbed gas was emitted, would be of importance in connection with the soundness of castings, as referred to by Sir Gerard Muntz, especially those used for hydraulic work. The work of Sievert and his school on the solution of gases in the simple metals threw some light on this question.

Mr. WALTER, in reply to the discussion at the meeting, wrote that he was extremely interested in the large amount of data with regard to melting costs which had been given, but at the same time regretted that it was hardly possible to compare the figures given on any particular basis, owing to the differences in the composition of the alloys melted and the variations in the type of work dealt with. He hoped, however, that this difficulty might be overcome in future by closer collaboration amongst the various investigators on this subject, and, possibly, by the adoption of standard tests on the melting of some of the commercial alloys in certain sizes of pots, which tests might be taken as standards of comparison for the various forms of fuel employed.

In reply to the question of Sir Thomas Rose, with regard to the figure of gas consumption of 7·6 c. ft. per lb. given on p. 198, as compared with that of $5\frac{1}{2}$ c. ft. as obtained at the Mint, he would mention that the former figure represented that obtained when melting brass in small pots of 50-lb. capacity for the production of sand-castings and included all stand-by losses met with in such work, owing to the metal having to remain in the molten state in the pots until moulds were ready. The total time spent in this way often amounted to as much as 50 per cent. of the actual time employed in melting, whereas in the case of the $5\frac{1}{2}$ c. ft. figure obtained at the Mint, this represented the consumption for continuous melting for pouring into strip. When working under the latter conditions with furnaces of this capacity, this figure would be reduced to approximately $4\frac{1}{2}$ c. ft. per lb. in the case of the melting of 60 : 40 brass.

Regarding the comparative costs of melting by means of high-pressure gas and low-pressure gas with air under pressure, speaking generally it was his experience that, in the case of the latter method as applied to continuous melting, the fuel cost was 15 to 20 per cent. lower than in the case of the former method. But for the smaller sizes of pot furnaces, it was generally found that the saving in fuel so obtained was more than outweighed by the extra cost of maintaining the furnace linings in a good state of repair, and also by the increased standing charges when the furnaces were down for relining. In this connection he would mention that in the case of an installation of 160 lb. air-blast pot furnaces installed some time ago for the melting of phosphor bronze, it was found that, owing to the extreme concentration of combustion which could be obtained with this system, the efficiency was such that a figure of slightly less than $3\frac{1}{2}$ c. ft. per lb. of metal melted was obtainable.

Owing, however, to the extremely high flame temperature employed, it was found necessary to renew completely the inner brick linings once each week at a cost of 35s., this at the same time involving the shutting down of the furnace for a complete working day to allow for cooling. Further, it was found that, when working at a reduced speed with a lower flame temperature and with a gas consumption of $5\frac{1}{2}$ c. ft. per lb. metal melted, the linings, with patching-up at the end

of each week, would last from six to eight weeks. In the case of a similar installation of high-pressure gas-heated furnaces with brickwork linings, and melting metal of similar composition, the gas consumption amounted to 6 c. ft. per lb. metal melted, and with fettling at the end of each week, the linings were found to stand up for upwards of six months. In another instance where a battery of twelve 50-lb. high-pressure gas-heated furnaces were employed for medium-cored sand-castings in 60 : 40 metal, it was found that, allowing for all stand-by losses, the gas consumption amounted to 7·6 c. ft. per lb. of metal melted, whilst in the case of a similar installation of six 60-lb. pit furnaces fitted with low-pressure gas and air-blast furnaces, the overall gas consumption was found to average slightly under 7 c. ft. per lb. metal melted. In the case of the latter installation, however, it was found that the increased cost of maintenance of burners, cones, and linings more than outweighed the saving in fuel, the linings in the former case having been in use for upwards of two years and being still in a good state of repair, whilst in the latter case it was found necessary to replace the linings after seven months' working.

Where the melting operation was continuous, and a high speed of melting could be maintained, he had found that the low-pressure system, despite its increased maintenance cost, had many advantages, and provided that the linings could be frequently and quickly renewed at a moderate cost, such a system was found to be the more economical, but in the case of melting in small pots intermittently the high-pressure furnace was found to be more satisfactory. He thought that a considerable amount of work had yet to be done with regard to the obtaining of a furnace lining which was highly refractory, and at the same time capable of being heated up quickly and withstanding the fluxing effect of spilled metal, as on the solution of this problem the future of the gas-heated furnace was, in his opinion, largely dependent.

In reference to the life of pots, he was rather surprised at the high figure of 80 heats which had been obtained by Mr. Yates, as this was considerably in excess of the number which he had found it possible to obtain in pit furnace work with either of the systems referred to, and he would be glad to know whether the pots referred to were of special composition.

Another question, which had been asked by Mr. Hartley, referred to the high figure of gas consumption of 7·6 c. ft. per lb. given in Table IV., and in reply he (Mr. Walter) would mention that this was due to the high stand-by losses in this particular class of work, as would be seen by referring to the full details of this test which had been lodged with the Secretary. In reply to a further question asked by the same contributor to the discussion, the higher figure of 6 c. ft. per lb. given for strip, ingot, and billet work, as compared with the figure of 4½ c. ft. per lb. for continuous melting in 50-lb. pots, was explained by the fact that the pots employed in the former case were of 160-lb. capacity, and which, owing to the decreased heat conductive surface per lb. of

metal contained, were found to require an increased gas consumption of 15 to 20 per cent. With regard to the latter figure of $4\frac{1}{2}$ c. ft. per lb. being high, he (Mr. Walter) could only agree that it was, from a thermal efficiency point of view, but it had been found inadvisable to work with a higher flame temperature, owing to the difficulty of obtaining a sufficiently highly refractory material which would stand for any length of time. He would like to mention that it was possible to obtain higher flame temperatures by splitting up the burner into a number of smaller units, but owing to the difficulties referred to above it was found inadvisable to do so in practice.

Reference had also been made by Dr. Rosenhain to a point which he (Mr. Walter) considered to be one of utmost importance, and that was the fact that the various types of gas-heated pit furnaces had been compared with the simple form of direct-fired coke furnace, which was in all probability, from a thermal point of view, one of the most inefficient forms of melting furnaces to be met with. In this connection he (Mr. Walter) was of the opinion that, had the coke-heated furnace received the attention which the gas-heated furnace had received during the past few years, the gas furnace would still have to be very considerably improved to compete with this form of solid fuel, notwithstanding its many disadvantages.

Further, Dr. Rosenhain had made mention of the possible advantages to be obtained by the employment of a non-conductive packing in order to reduce to a minimum the loss of heat to the surrounding earth. He (Mr. Walter) had carried out a considerable amount of experimental work in this connection when fixing the dimensions of the brickwork settings of melting furnaces, and he could say that a layer of insulating material supported by an outer brickwork wall had proved to be of considerable advantage. The thickness of this layer required to be varied to suit the particular conditions obtaining. He was also of the opinion that whilst the conductivity for heat of firebrick material had been made use of in many ways, its effect in reducing the thermal efficiency of furnaces by conducting away the heat to the outer radiating surfaces had, in many instances, not been sufficiently appreciated.

Mr. Walter, replying to the written discussion, wrote that Mr. Harvey had referred to his (Mr. Walter's) remarks regarding the compressing of both gas and air for high temperature work, and he wished to say that, although he had found that there was no difficulty in obtaining the high temperatures required for this purpose by compressing the air only, he had also found that the advantages obtained by having both gas and air under a positive controllable pressure to be very considerable, and at the same time allowed of a system being made use of which was more automatic and free from risks of explosions occurring in the supply pipes should the burner tubes, through any accident, be choked with spilled metal.

In reply to the questions asked by Mr. Johnson (Birmingham),

he wished to say that, with regard to the absorption of metal by the material of the crucible itself, he had in some instances observed the small particles of metal adhering to the inner surface of the crucible both in the case of gas and coke heating, but he thought that it was questionable whether it would pay to recover these metallic particles.

With regard to the time required for obtaining a first " heat " of metal from a high-pressure gas-melting furnace, he had usually found that two hours was a good average figure, with the furnace running " full on " and correctly adjusted.

Regarding the question of the value of the metal recoverable from the ashes from solid fuel-fired furnaces, he had allowed in the figures of loss given for the major portion of this, which consisted of spillings which were picked out of the ashes before leaving the foundry ; but with regard to the small quantity of metal which could only be extracted by grinding and washing, no allowance had been made owing to the difficulty of ascertaining its true value.

In reply to the question as to whether the percentage loss had been calculated on remelted metal or on alloys made from virgin metals, he would state that the figures of loss given in the case of sand-castings were estimated on the assumption that each heat consisted partly of ingot metal and scrap, and partly of returns from previous heats, in the form of ridges and gits. In the case of strip and billet work, it was assumed that the heat consisted of virgin copper and spelter and a small percentage of returns from previous heats. This he found to agree very well with ordinary foundry practice, and the figures given in Table III. (col. 5) were those obtained from actual tests.

Regarding the question of the noise produced by high-pressure gas furnaces, he could only say that this in some instances was greater than that produced by the air-blast furnace, but he had on no occasion received any serious objections from workmen using these high-pressure furnaces.

He was extremely interested in the results of the experiments referred to in the communication of M. Le Chatelier, especially in regard to the mixture velocities given as being found to be the most suitable to work with, as these confirmed those obtained from a lengthy series of experiments which he (Mr. Walter) had carried out. Further, the method of admitting the mixture into the furnace through an annular space surrounding the pot, with a view to obtaining a more uniform distribution of heat and long life of linings and pots, was a point of considerable interest, although, as this distinguished honorary member mentioned, it was hardly practicable in the case of melting furnaces, owing to the ease with which this annular space became choked with spilled metal. He (Mr. Walter) had employed an annular perforated plate at the base of the combustion chamber for this purpose in the case of the heating of tubular liners, and by this method had obtained the most uniform heating possible.

OBITUARY.

Sir Henry Arthur Wiggin, Bart., Vice-President of the Institute since its foundation in 1908 until his retirement from the office in 1912, died suddenly on May 2, 1917, at his residence, Walton Hall, Eccleshall, Staffordshire, on the eve of his sixty-fifth birthday. He had been in indifferent health for some time, but was well enough on the day before his death to attend a meeting of the North Staffordshire Railway Company, of which he was Chairman.

The deceased baronet, who was the eldest son of the late Sir Henry Wiggin of Harborne, was born on May 3, 1852. He was educated at King's College School, London, and at M. Sellig's school at Vevey, Switzerland. On leaving Switzerland he proceeded to the Royal Mining Academy, Freiberg, Saxony, but was there only a few months in consequence of the outbreak of the Franco-Prussian War, which resulted in the academy being closed. Subsequently he went to the Royal School of Mines in London, where he studied Metallurgy under Dr. Percy. In 1871 he entered his father's firm of Henry Wiggin & Co., metal refiners, George Street, Birmingham, and four years later he was taken into partnership. When the business was converted into a private limited company in 1892 he became Managing Director, and this position he held for seven years. During this time he had resided at Harborne, but in 1899 he purchased the Walton Hall estate, and went to Staffordshire to live. He relinquished the active management of the business in Birmingham, but remained to the last a director of the company.

For many years Sir Henry took great interest in the public work of the city of Birmingham, but it was the social and philanthropic aspects which mostly appealed to him. He entered the Town Council as a representative of Rotten Park Ward in 1890, and was appointed a member of the Gas Committee.

Largely interested in the pursuit of agriculture, Sir Henry took an active share in the work of the Birmingham Agriculture Exhibition Society for forty years. He was elected a guardian of the Birmingham Assay Office in 1883, and a warden a year later; he was chairman of Messrs. D. F. Taylor & Co., Newhall Hill; a director of Messrs. J. B. Brooks & Co., as well as of the North Staffordshire Railway Company. Sir Henry was appointed a magistrate for Staffordshire in 1880, at which time Harborne formed part of that county; in 1895 he became a Deputy Lieutenant, and he served as High Sheriff of the county in 1896. From the time he went to Walton Hall to live, in 1899, he took a keener interest in Staffordshire affairs, and served for some years on the County Joint Committee, and also as Chairman of the Eccleshall Bench.

Sir Henry, who was deeply interested in natural history as a hobby, was a man of sound business ability, and highly respected in the city and in Staffordshire.

He married in 1878 the youngest daughter of the late Mr. C. K. Cope of Kinnerton Court, Radnor, and the title now devolves on their eldest son, Captain Charles Richard Henry Wiggin, Staffordshire Yeomanry, who last year married a daughter of the late Sir W. Jaffray.

SECTION II.

ABSTRACTS OF PAPERS
RELATING TO THE NON-FERROUS METALS AND THE INDUSTRIES CONNECTED THEREWITH.

CONTENTS.

PROPERTIES OF METALS AND ALLOYS.

CONTENTS.

I.—*PROPERTIES OF METALS.*

Aluminium, Action of Acids on.—Further experiments on the action of acetic acid on aluminium are described by R. Seligman and P. Williams,* the present paper dealing with acids of lower concentrations. With 1 to 5 per cent. acid the attack is largely hindered by the formation of a protecting skin. The accumulation of products of reaction has a great influence in the case of dilute acids, the rate of attack increasing with time. The nature of these products has not been determined, but they must be volatile, as old acid retains its increased activity on distillation.

Acetic acid of from 5 to 60 per cent. strength becomes turbid as the action proceeds, and no adherent deposit is formed. The turbidity disappears on standing or on the addition of dilute hydrochloric acid. Solutions containing only 0·2 per cent. of acetic acid are turbid, and do not clear on standing or with hydrochloric acid. Boiling dilute acetic acid always causes uniform, and not local, corrosion. Cold acids have little action, the rate of attack increasing with the dilution, but falling off rapidly after the initial attack. This action is usually uniform, but acid between 70 and 95 per cent. frequently causes pitting. Pitting is favoured by aeration, the attack in absence of oxygen being always uniform. Vessels used for such acids should therefore not be allowed to remain wet without cleaning, and the fact also explains the frequent corrosion of aluminium condensing worms at their lower parts.

The rate of attack is greatly influenced by the presence of other salts, chlorides having much more effect than bromides or iodides. With boiling 80 per cent. acid, the addition of 1 per cent. of sodium

chloride increases the rate of attack fifty times. Local pitting is increased by halogen salts, but retarded by sulphuric acid and completely prevented by the addition of only 0·1 per cent. of nitric acid. It may be possible to make practical use of this fact.—C. H. D.

Aluminium Rectifier.—A study of the behaviour of aluminium in an electrolytic cell has been made by A. L. Fitch,* and the results are discussed in accordance with a theory that a double dielectric is formed, one part of which changes with time on open circuit and the other with time on closed circuit. Any electrolyte which can liberate oxygen may be used, and any metal which forms an oxide of high resistance under these conditions should be able to replace aluminium as an anode.—C. H. D.

Antimony and Tellurium, Elasticity of.—The elastic constants of antimony and tellurium wires have been determined by P. W. Bridgman.† Warm antimony, forced through a steel die, forms wire, but continually breaks up into small pieces. If the pressure be rapidly raised to a sufficient extent above that required to produce flow, the antimony is suddenly expelled with explosive velocity in coherent wires of unlimited length, which may be caught in water. This point is probably the melting point of antimony under non-hydrostatic pressure. The wire thus produced is very brittle and must be handled with care. Tellurium wire is more easily obtained by slow extrusion, and the pressure has not been carried far enough to reach the explosive point. The temperature used was 330° C. for tellurium, higher for antimony, and pressures up to 15,000 kg. per cm.²

Bending tests are made by cementing one end of a wire into the chuck of a lathe, loading with a rider, and measuring the deflection of the free end. Torsional tests are made by cementing the wire coaxially to a glass fibre, twisting both together, and afterwards using the fibre as a torsion pendulum. It is not practicable to use the wire directly as a torsion pendulum, on account of its fragility. The following results are obtained, in C.G.S. units :

	Young's Modulus. E.	Rigidity. μ.
Antimony	7.8×10^{11}	2.0×10^{11}
Tellurium	4.1×10^{11}	1.54×10^{11}

The order of magnitude is similar to that of glass. Antimony is extremely anisotropic, as E is greater than 3 μ. Should such a substance actually exist, it would expand under pressure.—C. H. D.

Beryllium, Melting Point and Heat of Fusion of.—Using beryllium of 99·5 per cent. purity, G. Oesterheld ‡ finds the melting point to be

* *Physical Review*, 1917 [ii.], vol. ix. p. 15.
† *Ibid.*, 1917 [ii.], vol. ix. p. 138.
‡ *Zeitschrift für anorganische Chemie*, 1916, vol. xcvii. p. 1.

1278°±5° C., the form of the heating and cooling curves showing that an impurity is present. Magnesia crucibles are used, in an atmosphere of hydrogen. Carbon is certainly present.

A calculation of the heat of fusion by Crompton's rule : atomic weight × heat of fusion ÷ absolute melting point = 2, gives the value 341 calories per gramme, whilst an approximate determination from the duration of the arrests when compared with an equal volume of gold gives the value 277 calories. Beryllium has the greatest heat of fusion of any metal, in accordance with its low atomic weight and high melting point.

It should be noted that the quantity of metal used for the thermal measurements was only 0·2 gramme.—C. H. D.

Cold-Working.—A paper by P. Ludwik * seeks to show that the phenomena of cold-working are not explicable by Beilby's amorphous hypothesis or by Tammann's translation hypothesis. In the experiments, copper, aluminium, zinc, tin, and lead wires are hardened by torsion. The greater the amount of mechanical hardening, the lower as a rule is the temperature at which softening takes place on annealing, or the shorter the time required for annealing at constant temperature. There is, however, no constant relation, which is the same for different metals. With lead, the removal of the load for even a few seconds brings about an appreciable softening. The internal friction may either increase or decrease on cold-working, according to the temperature, and the degree and velocity of cold-working.—C. H. D.

Contact Resistances.—The contact resistance between a surface of zinc and an electrolyte has been examined by N. K. Chaney.† The resistance, which is very small on immersion, rises with measurable rapidity to a large value. It forms the principal part of the resistance of a dry cell at low current density, but as soon as the latter exceeds a certain very small value the contact resistance diminishes or disappears, increasing again slowly when the circuit is opened. The effect is attributed to the presence of a layer of hydrogen, produced by local action. Rubbing or exposure to air lowers the resistance temporarily.

A theoretical paper, dealing in part with phenomena of the same kind, is contributed by W. C. Arsem.‡—C. H. D.

Copper, Effect of Oxide on Recrystallization of.—The effect of oxide on the growth of crystal grains in the annealing of cold-worked copper has been examined by C. H. Mathewson and G. V. Cæsar,§ who used specially prepared electrolytic copper, made into ingots by casting under borax. When copper containing even 1 per cent. of cuprous oxide is stirred beneath a borax flux, practically the whole of the oxide

* *International Journal of Metallography*, 1916, vol. viii. p. 53.
† *Transactions of the American Electro-chemical Society*, 1916, vol. xxix. p. 183.
‡ *Ibid.*, p. 207.
§ *International Journal of Metallography*, 1916, vol. ix. p. 1.

passes into the flux. The ingots are rolled down to one-third of their thickness. Annealings are performed at 700°, 775°, 850°, and 925° C. respectively for an hour. Cold-worked specimens containing oxide are best etched first with ammonia and hydrogen peroxide, and then lightly with acid ferric chloride. With 0·05 per cent. of oxygen the growth of grains is greatly retarded, the annealing temperature having to be about 150° higher to produce the same effect. Higher proportions of oxide have a much greater retarding effect. Scleroscope tests show that, after the initial softening of a cold-worked metal due to recrystallization has taken place, there is very little further softening to correspond with the growth of crystal grains as the annealing temperature is raised.— C. H. D.

Crystals, Volatilization of.—The volatilization from several crystals, including metallic zinc and silver, has been examined by M. Knudsen.[*] The crystal is held in a metal clamp, and so covered with platinum foil that only a small area of a natural face or cleavage is exposed, and the whole is then introduced into the side arm of a spherical glass vessel, in such a way that the face exposed forms as nearly as possible a part of the surface of the sphere. The bulb is then evacuated and cooled by liquid air while the crystal is warmed electrically. The metallic vapour condenses on the glass, and the distribution follows the cosine law. The exposed surface of the metal becomes granular, whilst the part protected by the platinum foil is almost completely unchanged.—C. H. D.

Electrical Carriers, Mass of.—An attempt has been made by R. C. Tolman and T. D. Stewart [†] to determine the mass of the carrier of electricity in copper, silver, and aluminium. Coils of wire are rotated at a high speed and suddenly brought to rest, a sensitive ballistic galvanometer being used to measure the pulse of current produced at the moment of stopping by the inertia of the electrons. For all three metals, the mass of the carrier comes out somewhat larger than the accepted mass of a slow-moving electron in free space. There still remain, however, certain sources of error in the apparatus which have to be eliminated before the results can be fully accepted.—C. H. D.

Emulsions of Molten Metals.—A short paper by H. W. Gillett [‡] deals with the emulsions which may be formed by molten metals. Thus aluminium swarf readily melts to globules which refuse to coalesce owing to the presence of a coating of oxide, and the flouring of mercury is due to a similar cause. Blue powder in zinc distilling is a similar product. Other emulsions are those of gases in cast metals, and the liquid mixtures of lead with a copper alloy in plastic bronzes. It is

[*] *Annalen der Physik*, 1917 [iv.], vol. lii. p. 105.
[†] *Physical Review*, 1917 [ii.], vol. ix. p. 164.
[‡] *Journal of Physical Chemistry*, 1916, vol. xx. p. 729.

suggested that such materials offer interesting applications of the chemistry of colloids.—C. H. D.

Films, Resistance of Metallic.—According to experiments by S. Weber and E. Oosterhuis,* thin metallic films are conveniently prepared by sublimation on to glass in a high vacuum. The thickness of the film is calculated from the loss of weight of the heated wire and the area covered by the deposit. For tungsten the relation between temperature and rate of evaporation is definitely known. The conduction of electricity by a platinum film becomes perceptible at a thickness of 1·645 $\mu\mu$, a black deposit being then visible. A rapid increase of the specific resistance occurs when the thickness falls below 7· $\mu\mu$. Tungsten shows a perceptible conduction at 0·5 $\mu\mu$, the sudden change occurring at 2·5 $\mu\mu$. With silver, conduction only appears at about 6·5 $\mu\mu$, the sudden change being at 25 $\mu\mu$. Very thin layers of silver are coloured. The conductivity does not change with time at atmospheric temperatures, but on heating to 130° the resistance increases very greatly.—C. H. D.

Gold, Volatility of.—As a result of experiments on the volatility of gold in various atmospheres at high temperatures the following conclusions are drawn by W. Mostowitsch and W. Pletneff.†

1. Chemically pure gold is not volatile in atmospheres of pure air, oxygen, nitrogen, carbon monoxide or dioxide, at temperatures between 1100° and 1400° C.

2. Chemically pure gold is volatile in hydrogen. Results from one series of experiments using 400 mgrm. of gold were as follows :

Temperature (° C).	Duration of Heating.	Loss (Mgrm.).	Loss per Cent.
1250	25 minutes	0·22	0·055
1300	,,	0·35	0·090
1350	,,	0·42	0·105
1400	,,	0·98	0·250

The volatility becomes noticeable at 1250° C. and increases with temperature.

The quartz boat and the heating tube in which the gold was heated were coloured an intense red. With other gases than hydrogen no colour was observed.—S. L. A.

Grain Growth.—A paper by Z. Jeffries ‡ deals with the growth of crystal grains. The " germinative temperature " is defined as the

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* *Proceedings of the Royal Academy of Sciences*, Amsterdam, 1917, vol. xix. p. 597.
† *Metallurgical and Chemical Engineering*, Feb. 1917, vol. xvi. (No. 3), pp. 153–4.
‡ *Bulletin of the American Institute of Mining Engineers*, 1916, p. 2063.

minimum temperature at which two adjacent grains can coalesce to form a larger grain. The temperature is lower the longer the time allowed. In one case the author calculated that 37,500,000 individual grains were absorbed by one germinative grain in 10 seconds. More rapid heating may prevent the formation of very coarse grains. Whilst foreign substances, such as oxide in copper or pearlite in steel, retard grain growth, they raise the germinative temperature and reduce the time required for grain growth, and actually favour the formation of a few very large grains. The size of grain before deformation has a marked effect on the selective grain growth during annealing. A small initial grain conduces to the formation of very large grains at the germinative temperature. The formation of very large grains at that temperature depends on the presence of fairly uniform grains with a temperature gradient, or of a uniform temperature with a deformation gradient, or of a combination of the two.

The same subject is discussed by H. M. Howe,[*] who points out that grain growth is favoured by fineness of grain, owing to the increased boundary surface, and by irregularity of grain, which favours absorption. The limit to grain growth so often observed is only apparent, the grain boundaries becoming diminished and the inequality of grain size lessened, so causing a retardation, but no real arrest, of growth. Exaggerated growth only occurs at the junction of germinant and inert grains. Wire-drawers observe that the slight deformation in the straightening process causes marked coarsening on annealing, whilst the severe deformation involved in wire-drawing does not.—C. H. D.

Magnesium.—An account of the metallurgical position of magnesium is given by W. M. Grosvenor.[†] The metal is used as a scavenger in the manufacture of alloys, on account of its great affinity both for oxygen and nitrogen, as an alloying metal, especially with aluminium, and for illuminating purposes, especially in military work and in photography. The pre-war price was about 6s. a pound (in the United States), but since the war 30s. and even 40s. have been paid. The German material, in smoothly finished rolled bars, was often not above 96 per cent. purity, and rarely exceeded 98 per cent. The price is governed by the demand on the part of alloy manufacturers, the quantity required for any charge of alloy being small, whilst the effect is most valuable. Before the war nearly the whole supply for Britain and France as well as the United States came from Germany. All three countries are now producing the metal. A much larger production may be expected when magnesium comes to be used in place of aluminium, and not merely as an addition. It makes excellent castings, machines easily and well, is one-third lighter than aluminium, and may be hot-rolled to a tensile strength of 35,000 lb. per sq. in., or cold-rolled to a much higher strength. In addition to the two well-known processes for its manufacture (action

* *Bulletin of the American Institute of Mining Engineers*, 1916, p. 2111.
† *Transactions of the American Electro-chemical Society*, 1916, vol. xxix. p. 521.

of sodium on fused magnesium chloride and electrolysis of a fused double chloride) four other processes are in the patent stage, namely, reduction by carbon, which yields a black powder at a very low cost ; electrolysis of magnesium oxide in a suitable solvent ; reduction of fused magnesium chloride by aluminium ; and the reduction of the oxide or carbonate to slag-forming residues.—C. H. D.

Magnetic Hysteresis.—A theoretical paper by J. R. Ashworth [*] deals with the application of Van der Waals' equation to the subject of magnetic hysteresis. The three stages of magnetization correspond with the three stages of the vaporization curve of a fluid. The temperature at which ferromagnetic properties change to paramagnetic properties corresponds with the critical temperature in vaporization. Fluids, however, do not exhibit hysteresis. The treatment of the subject is mathematical.—C. H. D.

Metal Coatings.—The structure of metallic coatings obtained by the Schoop process has been examined by H. Arnold.[†] The single metallic particles are oval, with a thread-like tail. On striking a surface these particles are flattened and form thin discs, so that transverse sections show a finely laminated structure. The adhesion of successive particles is purely mechanical, and true welding does not take place. This is confirmed by the fact that successive spraying with zinc and copper does not give rise to any formation of brass.—C. H. D.

Metallic Arcs.—In the course of a study of unstable states in electric arcs, W. G. Cady [‡] has observed that with silver, copper, or mercury anodes and a silver cathode, it is possible to obtain an arc at the anode while there is still a glow at the cathode. The appearance of this anode arc does not change when the arc phase sets in at the cathode. It is doubted whether an arc is possible from a pure metal. A cathode of pure silver may be heated by the glow discharge in nitrogen nearly, if not quite, to the boiling point without the formation of an arc. A tungsten anode was used. The admission of a little oxygen started an arc, but in its absence the silver would vaporize freely without arcing. Similar observations have been made with copper and iron, the arc never starting from the clean metallic surface, although on reaching the fringe of impurities surrounding the molten metal an arc was formed. It is possible that some particles of foreign substance may be necessary for the starting of an arc.

A description of several forms of improved tungsten arc is given by W. A. Darrah.[§]—C. H. D.

Metals, Change of Potential of.—The fact that such a metal as magnesium might become cathodic to such another as zinc was observed by

* *Philosophical Magazine*, 1917 [vi.], vol. xxxiii. p. 334.
† *Zeitschrift für anorganische Chemie*, 1917, vol. xcix. p. 67.
‡ *Transactions of the American Electro-chemical Society*, 1916, vol. xxix. p. 593.
§ *Ibid.*, p. 612.

C. M. van Deventer,* the condition being that the magnesium was immersed in a mixture of alcohol and water whilst the zinc was in dilute sulphuric acid. Further investigation now shows that the change of potential is always due to the formation of a layer of insoluble and badly conducting salt. Tin may become cathodic to lead even in the absence of alcohol. Plain aluminium is cathodic to zinc, whilst amalgamated aluminium is strongly anodic to zinc. An attempt is made to explain these facts.—C. H. D.

Molten Metals, Thermo-Electric Properties of.—The thermo-electric power of bismuth in the solid and liquid states has been measured by C. R. Darling and A. W. Grace.† Unlike other metals, bismuth exhibits a marked discontinuity at the melting point. Curves obtained by using silver, copper, and nickel wires all show an abrupt change of direction at the melting point of bismuth.—C. H. D.

Palladium, Melting Point of.—A note by G. Holst and E. Oosterhuis ‡ states that if the melting point of palladium be taken, as usual, as $1549°$ C., the constant c_2 in Wien's formula becomes $14,465 \pm 5$. If, on the other hand, this constant be assigned its value, $14,300$, derived from other researches, the melting point of palladium becomes $1557°$ C. —C. H. D.

Passivity.—A general account of the passive state of metals, with very full references to the literature, is given by C. W. Bennett and W. S. Burnham.§ The authors adopt the hypothesis of the formation of an oxide at the surface of the passive metal. The passive state is one in which the metal dissolves slowly, the oxide being itself unstable, but rendered stable by absorption into the metal. The oxygen film theory assumes that active oxygen can remain in contact with a metal without oxidizing it, iron or magnesium, for instance, being easily rendered passive, whilst they are acted on by atmospheric oxygen.

An illustration of the stability produced in an otherwise unstable substance is given from the behaviour of cupric hydroxide, which is readily decomposed by boiling alone with water, but remains stable on boiling in presence of a manganese salt or if absorbed by wool. The quantity of oxide required for protection is very small, and it is not formed by direct oxidation, but by the formation of ions of higher valency in the solution. All the facts of passivity are regarded as being explicable on this hypothesis.—C. H. D.

Permanganates, Reducing Action of Metals on.—It has been noticed by W. Foster ‖ that most finely divided metals, including gold and platinum, reduce dilute, neutral solutions of potassium permanganate,

* *Zeitschrift für physikalische Chemie*, 1916, vol. xci. p. 687.
† *Proceedings of the Physical Society*, 1916, vol. xxix. p. 82.
‡ *Proceedings of the Royal Academy of Sciences*, Amsterdam, 1917, vol. xix. p. 549.
§ *Transactions of the American Electro-chemical Society*, 1916, vol. xxix. p. 217.
‖ *Chemical News*, 1917, vol. cxv. p. 73.

the solution becoming alkaline. Silver acts rapidly. Tungsten also acts rapidly, but the solution remains neutral. Mercury decolorizes the solution very quickly, the metal being oxidized.—C. H. D.

Plastic Flow.—A paper by E. C. Bingham * deals with the plastic flow of clays and similar materials, but the theoretical discussion has some bearing on the plastic flow of crystalline solids.—C. H. D.

Platinum, Volatilization of.—Further experiments by G. K. Burgess and R. G. Waltenberg † show that each impurity in commercial platinum crucibles (iridium, rhodium, iron, silicon) exerts its influence independently on the volatilization. The loss of weight is negligible below 900° C., even with iridium up to 3 per cent. Below that temperature there is frequently a gain in weight, owing to oxidation of iron. The loss above 900° is greatly increased by the presence of iridium, but reduced by the presence of rhodium. Platinum will take up silica in an oxidizing atmosphere at 1000° C. Such losses as are observed are repeated on repeated heating, with little diminution.—C. H. D.

Resistivity and Thermal E.M.F.—Determinations of electrical resistivity and thermal E.M.F. of certain metals and alloys are communicated from the Palmer Physical Laboratory by E. F. Northrup.‡

Resistivity (0° to 100° C.).—Specimens were all in the form of wire less than 0·23 cm. diameter. Measurements were made by means of a Kelvin double bridge. The specimens were heated in a tank of kerosene by a well-aged copper coil of the same length, placed close alongside. This coil served the double purpose of heating the bath, and by means of its resistance measuring the mean temperature of the specimen wire.

The resistivity of the same specimen at a given temperature was sometimes found to vary as much as 2 per cent. between successive determinations. This was attributed not to errors of experiment, but to the effect of heating or cooling between measurements.

The results are plotted as curves showing resistivity as a function of temperature. The values at 20° C. were as follows :

Material.			Resistivity at 20° C. (microhms per cm. cube).
Aluminium.	Magnesium.	Nickel.	
87·5	12·5	...	7·61
90·0	8·0	2	7·72
90·0	10·0	...	8·28
10·0	90·0	...	19·18
Aluminium (99·67)			2·75
Magnesium			4·75
Calcium			5·32

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* *Bulletin of the Bureau of Standards*, 1916, vol. xiii. p. 309.
† *Ibid.*, p. 365.
‡ *Metallurgical and Chemical Engineering*, 1917, vol. xv. (No. 4), pp. 193–7.

Calcium has but slightly higher resistivity than magnesium. Although aluminium and magnesium both have low resistivity their alloys show a considerably higher value than either of the constituents. Many metals and most alloys when in the solid state will have resistivities which are dependent on past physical history, *e.g.* heat treatment. In the case of very pure metals, such as copper, platinum, nickel, drawn into wire and thoroughly aged by prolonged heating, the resistivity will become a function of temperature only, provided the temperature does not exceed that at which the ageing was done. This is important with regard to their use in pyrometry.

Thermal E.M.F.—The thermal E.M.F. of each of the above materials was determined against copper. It was found impossible to weld the junctions, so they were made by flattening the ends and binding with fine copper wire.

Material.			E.M.F. against Copper (microvolts).		
			Steam (100° C.).	Freezing of Tin (232° C.).	Freezing of Zinc (419°C.).
Aluminium.	Magnesium.	Nickel.			
87·5	12·5	...	245	682	1555
90·0	8·0	2	255	703	1635
90·0	10·0	...	226	692	1598
10·0	90·0	...	599	1374	2862
Aluminium (99·67)			372	930	2934
Magnesium			301	810	1737
Calcium			1080	...	...

The E.M.F. of a nichrome junction was determined with the following results :

Temp. °C.	Steam (100°).	Freezing Point of			
		Tin (232°).	Zinc (419°).	Antimony (630°).	Copper (1084°).
E.M.F. (microvolts).	2303·17	5970	10,535	15,065	30,796

The curve shows a slight inflexion between 300° to 500°, due probably to a critical point in nickel at 360°.—S. L. A.

Silicon, Electrical Properties of.—Further experiments on the abnormal thermo-electric properties of different preparations of silicon by F. Fischer and E. Baerwind * show that it is unlikely that the positive and negative varieties of silicon are allotropic modifications,

* *Zeitschrift für anorganische Chemie*, 1916, vol. xcvii. p. 56.

as the density of the two modifications is the same, and the thermo-electric power is independent of the rate of cooling from high temperatures. It is also shown that the presence of aluminium in the positive variety cannot be the cause of its peculiarity, as negative silicon may be converted into positive by fusion in a vacuum cathode ray furnace, in which the introduction of aluminium is impossible. It is most likely that the negative modification contains a small quantity of oxide in solid solution, but the difficulty of determining this by analysis is considerable. Pure silicon, free from oxide, would have a high positive value.—C. H. D.

Silver and Lead Chlorides, Reduction of.—The reduction of silver and lead chlorides by zinc has been examined by A. Gawalowski.* In ammonia, the silver is obtained as a grey, dendritic mass. Lead chloride in water yields crystalline leaflets of lead, whilst in presence of ammonia the lead is black and microcrystalline.—C. H. D.

Solids, Theory of.—The difficulties in the theory of the solid state arising from the coefficient of expansion are mathematically discussed by M. B. Weinstein.† New determinations, especially at low temperatures, are necessary before these difficulties can be overcome.— C. H. D.

Thomson Effect.—A method of determining the Thomson effect in wires is described by H. R. Nettleton.‡ The wire passes through two vessels at constant temperature, one being hot and the other cold. The two vessels are separated by a gap, and the inner ends are of metal 5 mm. thick, with which the wire makes good contact by means of solder. A detecting coil of thin copper wire surrounds the wire in the gap. Cotton-wool is used to protect against convection currents. A constant current is passed through the wire under test. On reversing this current, a change of resistance in the detecting coil is observed, and this measures the sensibility. If, at the same time as the reversal is made, the current is slightly altered to a suitable extent, a complete balance between the Joulean and Thomson heat is obtained, and there is no change in the resistance of the detector. The mathematics of the method is discussed, and results are given for constantan, manganin, and nickel brass.—C. H. D.

Tungsten Arc.—The behaviour of the tungsten arc under pressure has been examined by G. P. Luckey,§ nitrogen being used up to 30 atmospheres pressure. The melting point of tungsten under one atmosphere pressure was found to be $3623°$ absolute, apparently decreased to $3564°$ under 28 atmospheres. The temperature was measured

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* *Oesterreichische Chemische Zeitung*, 1916, vol. xix. p. 150.
† *Annalen der Physik*, 1917 [iv.], vol. lii. p. 203.
‡ *Proceedings of the Physical Society*, 1916, vol. xxix. p. 59.
§ *Physical Review*, 1917 [ii.], vol. ix. p. 129.

by means of a Holborn-Kurlbaum optical pyrometer, and the apparent increase may possibly be due to an increased absorption of the vapour surrounding the arc. The highest temperature attainable in the arc was found to be 4235° absolute at one atmosphere, and 5084° under 33 atmospheres. These temperatures are probably below the boiling point of tungsten in each case.—C. H. D.

Vapour Pressures.—The vapour pressures of zinc, cadmium, and mercury have been accurately determined by A. C. Egerton * by allowing the vapour of the heated metal to pass through holes of known diameter drilled in a diaphragm, usually of silica, and condensing the vapour on a cold surface and weighing it. A good vacuum is maintained by means of a charcoal tube cooled in liquid air.

At the melting point the vapour pressures of zinc and cadmium are very nearly equal, whilst mercury has a smaller value, and similar relations are observed throughout the series. The values of $\frac{dp}{dT}$ at the melting points are :

Zinc	$4\cdot41 \times 10^{-3}$ mm.
Cadmium	$3\cdot70 \times 10^{-3}$,,
Mercury	$2\cdot81 \times 10^{-7}$,,

and at the pressure of 2×10^{-6} mm. :

Zinc	$1\cdot25 \times 10^{-7}$ mm. at 502° absolute
Cadmium	$1\cdot39 \times 10^{-7}$,, 436° ,,
Mercury	$2\cdot81 \times 10^{-7}$,, 234° ,,

<div align="right">C. H. D.</div>

Wire-Drawing.—A general account of wire-drawing is given by A. T. Adam.† Ancient wire was not drawn, but was made by rolling metal into thin sheets and then cutting it into narrow strips. A rope of bronze wire, 15 ft. long and about 1 in. in circumference, was found at Pompeii and is now in the Naples Museum. It was quite modern in type, being made of three strands laid spirally, each strand being composed of fifteen wires twisted together. The actual drawing of wire is first recorded in Augsburg in 1351, but the first mention of the process in Britain is in 1565, when a number of foreigners came to England and obtained permission from Queen Elizabeth to manufacture wire.

The remainder of the paper deals with the drawing of steel wire.— C. H. D.

* *Philosophical Magazine*, 1917 [vi.], vol. xxxiii. p. 33.
† *Journal of the Society of Chemical Industry*, 1917, vol. xxxvi. p. 241.

II.—*PROPERTIES OF ALLOYS.*

Acid-Resisting Alloys.—Nickel alloys having an increased resistance to sulphuric acid have been prepared by R. Irmann.* The resistance of nickel to warm strong sulphuric acid is rapidly increased by alloying with copper, a maximum being reached when the two metals are present in equal proportions. Only nickel is dissolved. Tungsten-copper-nickel alloys are prepared by adding copper to molten tungsten-nickel, but as the tungsten is increased the power of dissolving copper is reduced. With 2, 5, and 10 per cent. of tungsten the quantity of copper alloyed becomes 67, 50, and 45 per cent. respectively. Alloys which are highly resistant to sulphuric acid are :

	Per Cent.	Per Cent.	Per Cent.
Nickel	78	70	75
Tungsten	2	5	10
Copper	20	45	15

These alloys have an electrical resistance higher than that of constantan. The tensile strength reaches 47 kg. per mm.² in the cast condition, and the alloys, especially the most resistant of them, roll well. These alloys are still further improved in acid-resisting and rolling properties by the addition of iron, and they are then conveniently prepared by adding ferro-tungsten to cupro-nickel. The most resistant alloy contains about 40 per cent. of copper, 4 per cent. of tungsten, and 4 per cent. of iron.—C. H. D. [See also abstract on Chromium-Copper-Nickel Alloys, p. 335.—ED.]

Alloys, Bibliography of.—A chart showing those binary alloys whose equilibrium diagrams have been investigated, accompanied by a list of references, has been evolved by C. Estes.†

Each binary system investigated is indicated on the chart by a number in a square, and under the same number in the list of references are given the references to the work of the various investigators of that system.

The list of references also includes ternary and quaternary systems.—S. L. A.

Aluminium-Zinc Alloys.—This system has been reinvestigated by O. Bauer and O. Vogel,‡ on account of the discrepancies between the results of other investigators, and the points which still remain obscure even in the full research of Rosenhain and Archbutt. Incidentally, the authors protest against the practice of using atomic percentages in thermal diagrams in place of percentages by weight.

The thermal analyses have been made in all cases with quantities

* *Metall und Erz*, 1917, vol. xiv. pp. 21, 37.
† *Metallurgical and Chemical Engineering*, March 1917, vol. xvi. (No. 5), pp. 273-282.
‡ *International Journal of Metallography*, 1916, vol. viii. p. 101.

of 200 grammes in unglazed porcelain crucibles. The freezing point curve agrees closely with that of Rosenhain and Archbutt. The eutectic arrest at 380° C. does not occur beyond 21·65 per cent. of aluminium under conditions of equilibrium. When observed further it is due to imperfect equilibrium. The horizontal at 256° C. ends between 70 and 80 per cent. of aluminium, so that the quantity of zinc held in solid solution in the γ-crystals diminishes from 40 per cent. at 443° to 25 per cent. at 256°. Between the composition of Al_2Zn_3 and the limit of the solid solution, γ and Al_2Zn_3 are in equilibrium above 256°, and $a + \gamma$ below that temperature. This is confirmed by microscopical examination.

The Brinell hardness varies with the heat treatment, reaching a maximum of 202 in a quenched alloy containing 50 per cent. of aluminium, and a maximum of 124 in an annealed alloy of 70 per cent. aluminium. Pure zinc is appreciably hardened by quenching. Alloys containing from 7 to 10 per cent. of zinc, largely used for light constructional work, are readily distinguished from aluminium by the formation of an adherent black coating on immersion for five minutes in 5 per cent. sodium hydroxide, aluminium remaining white. In an alloy containing 8·73 per cent. of zinc the best mechanical qualities for light sections are obtained by annealing between 300° and 400° C. Immersion in tap water causes blistering even on the second day in both aluminium and the alloys in the cast state. Cold-rolled aluminium blisters in about fourteen days, whilst the alloys remain free from blisters. Distilled water attacks the alloys with 7 to 10 per cent. of zinc more readily than pure aluminium. These alloys resist corrosion best after annealing between 400° and 500° C.

Both aluminium and the alloys are effectually protected against corrosion by tap water, sea water, or the atmosphere by immersion for two to four hours in a bath containing 2·5 per cent. of potassium carbonate, 2·5 per cent. of sodium bicarbonate, and 1 per cent. of potassium dichromate, heated to 90° to 95°.

The coating thus formed is not dislodged by bending or even by hammering.—C. H. D.

Amalgams.—The equilibrium between mixed solutions of sodium and potassium salts and liquid amalgams has been examined by G. McP. Smith and T. R. Ball.* The value of the equilibrium constant depends on the concentration of the amalgams, and values for this dependence have been determined. The heat of the reaction $KHg + NaCl = NaHg_n + KCl + (m-n)Hg$ is about -3000 calories.— C. H. D.

Bearing Alloys.—A long paper by R. Förg † describes bearing alloys of many different types. Alloys containing about 84 per cent. tin,

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* *Journal of the American Chemical Society*, 1917, vol. xxxix. p. 179.
† *International Journal of Metallography*, 1916, vol. viii. p. 68.

10 per cent. antimony, 5 per cent. copper, and 1 per cent. lead, or of similar composition, are regarded as the best for most purposes. Their physical and mechanical properties are not injured greatly by repeated remelting, the threads of tin oxide which are formed in very old alloys not affecting the properties seriously. They do not segregate even on slowly cooling, the relatively infusible copper-tin compound exerting an influence in preventing segregation. The hard crystals effectually prevent dragging of the ground-mass, even under heavy loads without oil.

Alloys containing zinc readily lose zinc on remelting. Alloys containing mercury are unsatisfactory for many reasons, which are obvious —C. H. D.

Beryllium, Alloys of.—The alloys of beryllium with aluminium, copper, silver, and iron have been examined by G. Oesterheld.* Carbon crucibles cannot be used for their preparation, as the carbide is formed very readily, so porcelain crucibles are preferred for alloys containing low percentages of beryllium, and magnesia, protected against the entrance of gases, for the richer alloys. The quantities used for the thermal analysis are very small, being only 2 grm. in simple systems and about 10 grm. in the more complex. The thermocouples are of very thin wire, only 0·10 mm. in diameter.

Beryllium and aluminium mix in all proportions in the liquid state, and the freezing-point curve consists of only two branches, with a eutectic point at 644° C. and 1·4 per cent. by weight of beryllium. Solid solutions are formed at the beryllium end of the series, containing up to 8 per cent. of aluminium. The diagram is otherwise quite simple. The microstructure is in accordance with the diagram. Beryllium crystals formed below 900° are more or less angular, but at 1000° they become rounded. The alloys must be very lightly polished, and the structure is usually visible without etching, but may be made more distinct by etching lightly with sodium hydroxide. For the analysis of these alloys, the separation of the two metals being difficult, advantage is taken of the fact that beryllium liberates about twice as much hydrogen as an equal weight of aluminium when dissolved in acid. A homogeneous portion of the small ingot being weighed, the quantity of hydrogen which it evolves is measured, and the composition is found by graphical interpolation.

It has not been found possible to prepare alloys of beryllium and magnesium, the two metals remaining quite separate even when thoroughly mixed. It is not certain, however, that the metals are actually immiscible, as magnesium boils below the melting point of beryllium.

Alloys of beryllium and copper yield a complicated diagram. Solid *a*-solutions are formed up to 1·5 per cent. of beryllium, the freezing point curve falling regularly to 4·2 per cent. Beyond this is a liquidus

* *Zeitschrift für anorganische Chemie*, 1916, vol. xcvii. p. 6.

of very complicated form, corresponding with the formation of a β-solution, with an indication of a possible compound Cu_2Be. There follows a short branch corresponding with a δ-solution, after which the liquidus rises rapidly, a δ-solution then extending from 25 per cent. to an unknown percentage of beryllium. The interval between the liquidus and solidus in the β region is small. There is a eutectoid point at 575° C., the β-solution breaking up into α and γ. The eutectoid alloy contains 5·9 per cent. of beryllium. Microscopically it closely resembles pearlite, and requires a high magnification for its resolution. Homogeneous alloys in this region are obtained by quenching.

The δ-solution contains a compound $CuBe_3$, but it has not been found possible to prepare alloys richer in beryllium. This constituent forms characteristic octahedral skeletons, which have a violet colour. The alloys are soluble in nitric acid, and the copper may be determined electrolytically.

Beryllium and silver yield a simple diagram, similar to that of the alloys with aluminium. There is a single eutectic point at 878° C. and 1·5 per cent. of beryllium, and solid solutions are only formed at the beryllium end of the series, the exact limits being uncertain. The alloys at this end of the series undergo some transformation at 748°, which is found by the thermal method, but is without influence on the microstructure. As beryllium does not itself exhibit any transformation near to this temperature, it is possible that a compound with a large number of beryllium atoms in the molecule is produced. The structure is visible without etching, on account of the differences of colour.

Beryllium forms a compound with iron, the composition of which is unknown. There is a distinct eutectic point at 1155°, and 9·2 per cent. of beryllium, after which the freezing-point curve rises to an unknown maximum. Solid solutions range from pure iron to 6·3 per cent. of beryllium. The γ–β change point of iron is lowered by beryllium, reaching a constant temperature of about 650° at between 4 and 5 per cent. The alloys are readily etched by dilute sodium hydroxide, the compound being coloured brown or black. The eutectic has a very fine and delicate structure. The proportions of the constituents suggest that the compound may have the composition $FeBe_2$. For analysis, the iron is estimated by titration with permanganate.

Beryllium occupies a special position in respect to the rules which Tammann has enunciated regarding the power of metals to form compounds with one another. Thus it forms two compounds and a complicated series of solid solutions with copper, whilst the alloys with silver, the next related element, are quite simple in character. On the other hand, both magnesium and aluminium show a complete similarity between their alloys with copper and silver respectively. The difference is perhaps attributable to the relation of beryllium to the non-metals boron and silicon.—C. H. D.

Brass, Failure of.—A long report by P. D. Merica and R. W. Woodward * deals with the failures in 60 : 40 brass observed in the new Catskill Aqueduct, the Minneapolis filtration plant, and the Panama Canal. Most of the material was the so-called manganese bronze, but other alloys of similar type failed in the same manner. Castings and large forgings have usually escaped, but failures of bolts, rods, flat bars, and plates have been very numerous. They are ascribed partly to internal stresses in the alloy as used, partly to faulty practice in flanging, &c., or in excessive tightening of bolts. Season cracking, of which interesting photographs are given, occurs when the initial stress in the outer layer exceeds the elastic limit. Such stresses are best measured by Heyn's method of removing outer layers by turning and measuring the change of dimensions. This method was first used by Howard at Waterstown Arsenal as far back as 1893. A convenient rapid method consists in planning out a deep slot along a round rod, so that the rod bends as the stress is locally relieved.

Failures due to overheating the metal have only been met with once or twice. The mercurous nitrate test is convenient for detecting high initial stresses, and in some extreme cases mere immersion in water is sufficient to cause cracking. The report is very fully illustrated.— C. H. D.

Brass, Influence of Arsenic on.—A very full investigation of the influence of arsenic on the structure and mechanical properties of brass is published by O. Smalley.† In the a-brasses, the presence of arsenic increases the coring, and as the percentage increases particles of free arsenide appear. With 1 per cent. of arsenic, the free arsenide forms a continuous envelope round the crystal grains. The fracture of an arsenical brass resembles that of a pure brass cast at a considerably higher temperature. Increasing arsenic has little effect on the tensile strength or on the hardness (Brinell or scleroscope) of 70 : 30 cast brass, but greatly reduces the ductility and the resistance to alternating impact. When such metal is cold-worked, the arsenide is broken up and drawn out into fine threads.

The mechanical properties have been further examined by subjecting half of each ingot to the treatment adopted for an 18-pounder cartridge case slab before cupping, that is, cold-rolling in three passes to 0·55 in., annealing at 600° C., reducing in two passes to 0·451 in., and re-annealing. The cast brass with 0·09 per cent. of arsenic gives consistently better results than brass free from arsenic, but any further increase injures the mechanical properties, although the alloys with arsenic even up to 1 per cent. are cold-rolled with equal ease. Cold work followed by annealing does not cause the complete removal of cores when arsenic is present, unless the work has been carried very far, in which case only minute specks of arsenide can be detected even

in the 1 per cent. alloy. The annealing temperature must be somewhat higher than for non-arsenical brass.

In alloys of the Muntz metal class, containing about 41 per cent. of zinc and 59 per cent. of copper, even very small quantities of arsenic have an injurious effect. The fractures are coarsely crystalline, the coarseness and depth of colour increasing with the arsenic content. The hot-working properties are not affected, although the ductility and resistance to impact of the hot-worked metal is very greatly reduced. The arsenide makes its appearance in the β constituent, and with increasing quantities forms films which produce intercrystalline brittleness. Arsenic is without influence in promoting any transformation of the β constituent.—C. H. D.

Brass, Recrystallization of.—An important paper on the recrystallization of a-brass after cold-working is contributed by C. H. Mathewson and A. Philips.[*] Thin strips of 70 : 30 brass are used, and their hardness is determined by means of the scleroscope, all the microscopic structures being photographed. Curves are given to show the relations between temperature of annealing, extent of previous deformation, and size of crystal grain. For a given amount of reduction in area of cross section by rolling, there is a definite temperature of maximum crystal growth, which moves towards lower annealing temperatures with increasing deformation. Thus the maximum at 750° C., when the reduction has been 2 per cent., moves in succession to about 650°, 550°, and 450° when the reduction is 8 per cent., 12 per cent., and 25 per cent. respectively. There is a large number of excellent photographs.—C. H. D.

Bronze, Annealing.—The behaviour on annealing of bronze containing from 4 to 8 per cent. of tin has been studied by C. H. Mathewson and P. Davidson.[†] The process of diffusion, equalizing the composition of the solid solution, occupies about the same time whether the alloy is simply cast or is also deformed by cold-working. Alloys which have been rendered homogeneous before cold-working become coarser in grain on annealing than alloys which have been cold-worked to a similar extent immediately after casting. The paper is illustrated by a large number of curves and photomicrographs.—C. H. D.

Bronzes and their Mechanical Properties.—The term bronze in its application to copper alloys is discussed by H. S. Gulick,[‡] who also deals with the general properties of copper-tin alloys, and of the component metals used in making the more complex bronzes.

The influence of antimony in small percentages is discussed, and increase in hardness, closeness of grain, and tensile strength, with lower-

[*] *Bulletin of the American Institute of Mining Engineers*, 1916, p. 1.
[†] *International Journal of Metallography*, 1916, vol. viii. p. 181.
[‡] *Foundry*, Feb. 1917, vol. xlv. p. 68.

ing of elongation, are attributed to it. It acts adversely on conductivity.

Manganese is stated to act as a deoxidizer and to increase the soundness of bronze castings. Increase in tensile strength and toughness, with only small lowering of elongation, are attributed to the presence of manganese. The influence of titanium is similar to that of manganese, whilst that of nickel in some special bronzes is beneficial in that it aids in forming a dense, close-grained structure and in lowering the rate of wear.

Iron is stated to increase the tensile strength and lower the elongation.

The properties of the following alloys are discussed—viz. gunmetal bronze, phosphor bronze, steam metal bronze, aluminium bronze, Tobin bronze, manganese bronze, and bearing bronze. Stress is laid upon the variability in physical properties of gun-metal, depending in large measure upon the method of casting the test-bar, that is, upon the size, shape, weight of riser, and rapidity of cooling.—F. J.

Cerium-Iron Alloys.—These alloys, which are technically important on account of their pyrophoric properties, have been investigated by R. Vogel.* The cerium used contained as much as 4·4 per cent. of impurities, mostly lanthanum, and gave the freezing point 775° C. There is a eutectic point at 640° and 5 per cent. of iron, cerium crystallizing without forming a solid solution. Beyond this point the freezing-point curve rises, corresponding with the formation of a compound $CeFe_2$, which has no stable melting point, but decomposes at 775°. This compound crystallizes in long prisms, which are non-magnetic at high temperatures, but become magnetic at 116° on cooling.

The compound formed at 775° is Ce_2Fe_5, which again decomposes at 1085°. The magnetic transformation temperature of this compound has not been determined. From this point onwards the freezing-point curve rises, corresponding with the crystallization of a γ solid solution which is non-magnetic and contains a maximum proportion of 15 per cent. of cerium at 1085° C. These alloys show a double polyhedral structure on etching, similar to that obtained by Ewen in pure iron. As the temperature falls the solubility of cerium in iron diminishes, and crystals of Ce_2Fe_5 separate. The γ–β and β–α transformation temperatures of iron are slightly raised by the addition of cerium in solid solution. The saturated solid solution becomes magnetic at 795° on cooling, whilst the thermal change is at 840°.

Owing to the transformations in the solid state, complicated structures are sometimes obtained, which are rendered evident by heat-tinting.

The hardness (determined very crudely according to the Moh scale) increases with increasing iron until the compound CeF_2 is reached.

* *Zeitschrift für anorganische Chemie*, 1917, vol. xcix. p. 25.

This and the compound Ce_2F_5 have nearly equal hardness (5, cerium being 2·5). The liability to oxidation is roughly in proportion to the percentage of cerium. The two compounds are pyrophoric, but require severe filing on account of their hardness. For this reason alloys containing some free cerium are preferred as pyrophoric alloys, the maximum being reached at about 70 per cent. of cerium.—C. H. D.

Chromium-Copper-Nickel Alloys.—The high resistance of alloys of chromium, copper, and nickel to corrosion has led D. F. McFarland and O. E. Harder [*] to study the general properties of this series. Of the three binary systems concerned, copper and nickel form a continuous series of solid solutions, chromium and copper are immiscible in the liquid state over a very wide range, and nickel and chromium give a freezing-point curve which passes through a minimum which may or may not be a eutectic point. The two latter systems have not been very well investigated. The thermal analysis of the ternary alloys has proved to be a difficult problem, and the results are reserved for later publication.

Chromium-copper alloys show partial separation of a second constituent on slow cooling if they contain 6 per cent. or more of chromium, but the addition of nickel increases the miscibility, so that when the amount of nickel is three times the quantity of copper, the alloys with chromium are homogeneous.

All the alloys are melted in an electric furnace under a layer of cryolite, and cast in heated iron moulds lined with asbestos and surrounded by non-conducting material. The products have to be analysed, as there is a considerable loss of chromium. The specific gravity decreases with increasing chromium. The Brinell hardness increases with the chromium, an alloy containing about 12 per cent. of copper, 57 per cent. of chromium, and 31 per cent. of nickel giving the Brinell hardness 228, comparable with that of a self-hardening tool steel. The modulus of elasticity and breaking load increase on the whole, although irregularly, with the chromium content. The elongation of the cast alloys is small, and the reduction of area inappreciable.

The resistance of the alloys to corrosion by acids and other reagents has been tested by determining the loss of weight. The results are plotted on triangular diagrams, and areas of minimum corrosion indicated by shading. As a rule, the ternary alloys are more resistant than the binary, but there are exceptions. Most of the resistant alloys appear to be rich in nickel, and to contain the copper and chromium in about equal quantities. No useful results could be obtained by measurements of electrolytic potential.

The microscopical examination leaves doubts as to whether the specimens were in a state of thermal equilibrium. The alloys of chromium and nickel have been described as containing a eutectic, and this interpretation is accepted, but the photographs do not bear

[*] *University of Illinois Bulletin*, 1916, vol. xiv. p. 10.

this out, the structures shown having every appearance of imperfectly diffused solid solutions. Alloys very rich in nickel are very coarse and porous. On the other hand, those rich in chromium are too infusible, and when copper and chromium together exceed the nickel, there is marked segregation. The alloys offering some prospect of commercial usefulness are therefore confined to a zone crossing the triangular diagram.—C. H. D. [See also abstract on Acid-Resisting Alloys, p. 328.—ED.]

Copper-Iron Alloys.—The equilibrium between copper and iron has been carefully investigated by R. Ruer and F. Goerens.* Although care was taken to exclude impurities, and analyses showed that the products contained not more than 0·01 per cent. of silicon and aluminium, 0·005 per cent. of hydrogen, and 0·03 per cent. of nitrogen, a freezing-point curve was obtained which was not horizontal within the limits of partial miscibility. That is to say, the system behaved as a ternary one. The cause of this abnormality has not been explained. Separation into two layers only takes place when the alloy is heated 20° C. or above its melting point, otherwise the two metals remain emulsified.

The limits of miscibility at the melting point are 23·8 and 85 per cent. of copper, within which range the freezing point falls from 1450° to 1375° C. This result is not due to undercooling.

There are three series of solid solutions. Several points in the equilibrium diagram remain very difficult to explain, and it does not appear that the abnormalities are to be attributed to experimental error.—C. H. D.

Deformed Metals, Recrystallization of.—Dealing especially with cold-worked *a*-brass, H. M. Howe † discusses the mechanism of recrystallization after plastic deformation. The etch-bands, which appear to represent the accumulation of amorphous material on the gliding planes, disappear on moderate reheating. Disintegration and re-orientation then take place, accompanied by the growth of the crystal grains. The mere relief of stress cannot account for much of the softening. The annealing temperature needed to cause nearly complete softening is lower, the greater the previous deformation and the longer the annealing period.—C. H. D.

Gold Bullion, Segregation in.—Many data from the assays of cyanide gold bullion are published by J. H. Hance.‡ It is found that drillings taken near an edge are very variable, but usually give higher assay values than the dip samples. The centre usually gives lower values, samples near the top giving slightly higher assays than those near the

* *Ferrum*, 1917, vol. xiv. p. 49.
† *Bulletin of the American Institute of Mining Engineers*, 1916, p. 1851.
‡ *Ibid.*, p. 299.

bottom. This also applies to dip samples. Small quantities of silver check segregation, and the addition of silver to ensure homogeneity, when the cyanide bullion does not already contain that metal in sufficient quantity, is recommended.—C. H. D.

Magnetic Alloys.—In the course of a study of the Kerr effect, S. G. Barker * has examined several non-ferrous alloys. Circular discs of the metals, 5 mm. in diameter and 0·5 mm. thick, were soldered to one pole of a large electromagnet. Polarized mono-chromatic light was then reflected from the surface and examined by an analyser. The experiments were chiefly directed to the determination of the saturation intensity. The non-ferrous alloys contained cobalt. No metallographic examinations were made. A cobalt-tin alloy, originally magnetic, was found to become non-magnetic in the course of three years, and the magnetism was not restored by heating to 100° C. for two days.—C. H. D.

Molecular Condition.—The relation between compounds and solid solutions is discussed by G. Masing.† It is concluded that the space-lattice of stable crystals containing little or no foreign material in solid solution must be composed of almost undissociated molecules. When the dissociation is greater there is a wider range of solubility in the solid state, but the converse is not necessarily true. That a physical property, such as the electrical conductivity, should pass through a maximum at the composition of a definite intermetallic compound in a series of solid solutions is only true if the property be equally affected by addition of either component, otherwise the maximum may occur at a composition differing from that of the compound.—C. H. D.

Resistance Alloys.—The electrical resistance of some new alloys containing copper and nickel has been determined by F. M. Sebast and G. L. Gray,‡ with a view to finding an alloy of high resistance and low temperature coefficient for precision work. Alloys for heating purposes have usually a high resistivity and moderate temperature coefficient. The best known are :

Name.	Components.	Resistivity. Microhms per Cm.^{3}	Temperature Coefficient per °C.
18 per cent. nickel brass	Copper, nickel, zinc	33·0	0·00031
Climax . . .	Iron, nickel	87·0	0·00067
Ferro-nickel . . .	Iron, nickel	28·0	0·00210
Krupp . . .	Iron, nickel	85·0	0·00070
Nichrome . . .	Iron, nickel, chromium	95·5	0·00043

* *Proceedings of the Physical Society*, 1916, vol. xxix. p. 1.
† *International Journal of Metallography*, 1916, vol. ix. p. 21.
‡ *Transactions of the American Electro-chemical Society*, 1916, vol. xxix. p. 569.

On the other hand, alloys for standard resistances must have very low temperature coefficients with moderately high resistivities. They must also have a low thermo-electromotive force against copper, and it is in this respect that most of the commercial alloys are deficient. Manganin is the most satisfactory alloy in this respect, having a thermo-electromotive force of 3 microvolts per degree, against 40 for constantan. The following are commonly used alloys of this class:

Name.	Components.	Resistivity. Microhms per Cm.^{3}	Temperature Coefficient per °C.
Manganin . . .	Copper, manganese, nickel	42	0·000011
Constantan . . .	Copper, nickel	50	0·000005
Ia Ia . . .	Copper, nickel	47	0·000005
Advance . . .	Copper, nickel	49	0·000018

The addition of chromium and of manganese to alloys of copper and nickel has now been tried, the component metals being melted together in an alundum crucible in an Arsem vacuum furnace, cast into a small cylindrical ingot, rolled cold, with occasional annealing, to 1·5 mm. diameter, and then drawn through steel dies to 0·25 to 0·50 mm. All wires were annealed after drawing. The resistances were determined by the fall of potential method.

The addition of chromium to copper only increases the resistivity slightly, and in a linear manner, indicating that solid solutions can only be formed to a very slight extent. The resistivity of nickel is rapidly increased by addition of chromium, indicating the formation of solid solutions.

The addition of chromium to copper-nickel alloys at first increases the resistivity, until a maximum is reached, and then diminishes it. The temperature coefficient varies in an inverse manner. The best alloy of the series has a resistivity of 112 and a temperature coefficient of 0·000078, and contains copper 71 per cent., nickel 12·5 per cent., chromium 16·5 per cent. This alloy should be commercially useful.

Manganese in any concentration increases the resistivity of copper-nickel alloys and diminishes the temperature coefficient. The best alloy of the series has a resistivity of 70 microhms per cm.^{3}, and a temperature coefficient of practically zero. It contains copper 55 parts, nickel 45 parts, manganese 15 parts. This is a better alloy than any at present in use for standard resistances.—C. H. D.

Silver Tellurides.—The alloys of silver and tellurium have again been studied by M. Chikashige and I. Saito.* Two definite compounds are found, of which one, Ag_2Te, gives a curiously acute maximum on the liquidus curve at 957°, whilst the other, to which the formula Ag_7Te_4

* *Memoirs of the College of Science*, Kyoto, 1916, vol. i. p. 361.

is assigned, exists in two modifications and decomposes without melting, the β-modification being formed from solid Ag_2Te and liquid at 443° C., and being converted into the a-modification at 403°. These two phases only correspond with short branches on the liquidus. The authors bring forward reasons for not accepting the simpler formula AgTe, but their tellurium was not very pure, and their photomicrographs are not very clear. The eutectic points lie at 32 per cent. Ag and 350° C., and at 87·5 per cent. Ag and 870° respectively. Solid solutions are not formed. The appearance of alloys containing about 70 per cent. of silver is such that it is suggested that they may have some technical value as ornamental cast alloys.—C. H. D.

Tin-Cadmium and Tin-Bismuth Alloys.—The electrical properties of these alloys have been carefully examined by Armin Bucher,* and compared with the microstructure. The alloys are cast into rods in absence of air by melting in a Jena glass tube in a good vacuum, lowering a narrow glass tube, sealed into at the upper end, into the molten mass, and then slowly admitting air to the outer vessel, so that the metal is forced up into the narrow tube, where it gradually solidifies. Cadmium and alloys rich in cadmium attack glass, so when they are cast it is necessary to coat the tube internally, fine alumina in suspension, as used for polishing, being found most suitable. For tin and bismuth it is sufficient to clean the tube with chromic acid and heat it in a flame. Rods 20 cm. long and 3 to 3·5 mm. thick are thus obtained.

The electrical conductivity is measured by means of a Kelvin double bridge. The temperature coefficient is determined from measurements at temperatures ranging from 18° to 164° C. The thermo-electromotive force is measured against pure silver, the end of the rod being threaded, and the silver wire wound between the threads of the rod and those of a brass nut.

The conductivity of the tin-cadmium alloys exhibits a discontinuity at 130° C., corresponding with the point already found by thermal analysis. This is not found in the pure metals, or in the alloys containing more than 97 per cent. of tin. The form of the conductivity and thermo-electromotive force curves indicates that tin holds about 3 per cent. of cadmium in solid solution, whilst at the cadmium end of the series about the same amount of tin is taken into solution. Three rods of cadmium were drawn into wire and again tested. The conductivity was in each case lower than that of the cast metal, and was not restored to its original value even by annealing for 96 hours at over 200° C. Drawn wire should therefore not be used for such experiments.

Microscopical examination shows that the solubility of tin in solid cadmium falls appreciably with falling temperature.

In the tin-bismuth series, the conductivity curve indicates a solubility of 1·5 per cent. of tin in solid bismuth. At the tin end of the series, the change of direction of the curve is not sufficiently abrupt to

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* *Zeitschrift für anorganische Chemie*, 1916, vol. xcviii. p. 97.

determine the limit of solid solution exactly, but the temperature coefficient curve, which consists of four branches, fixes the limit at 14 per cent. of bismuth. This curve also exhibits an abrupt change of direction at the eutectic composition. The curve of thermo-electro-motive force is of similar form. The properties of the alloys are changed by heating, a stable state being reached after a time. The abrupt change of properties at the eutectic composition is explained by the microscopic structure, alloys on the tin side of the eutectic being finely crystalline, whilst the presence of free bismuth, or of solid solutions rich in bismuth, makes the structure very coarse.

The thermo-electromotive force may be used as a sensitive test for the purity of bismuth.—C. H. D.

Tungsten-Molybdenum Alloys.—This series of alloys has been studied by Z. Jeffries,* the melting points being determined by an indirect method. A wire of the alloy to be examined is stretched between electrodes in an atmosphere of hydrogen, and current is passed until the wire melts, the number of watts required for fusion being observed. The apparatus is calibrated by making the same measurements with pure tungsten and pure molybdenum, the melting points of those metals being taken as 3300° C. and 2500° C. respectively. The melting points of the alloys are then determined by interpolation from the watts consumed. The melting-point curve is quite smooth, and indicates a continuous series of solid solutions. This is confirmed by microscopical examination, all the alloys forming homogeneous polygonal grains when care is taken in their preparation. The powdered metals, reduced by hydrogen, are sintered at 1300° C. in hydrogen, heated just short of the melting point by an electric current, and then rolled or swaged. The alloys are etched by a hot solution of hydrogen peroxide. Each grain of the alloys thus prepared represents about 1000 of the original particles of the powder.

Prolonged etching produces etch-figures, the form of which indicates that both metals crystallize in the cubic system. The curve of hardness passes smoothly through a maximum.—C. H. D.

III.—*METALLOGRAPHY*.

Etching Reagents.—A long list, with tables, is given by W. Guertler,† recording the reagents used in etching micrographic specimens, with the purposes for which each is most suitable.—C. H. D.

* *Bulletin of the American Institute of Mining Engineers,* 1916, pp. 1049 and 1225.]
† *International Journal of Metallography,* 1916, vol. viii. p. 228.

IV.—*INDUSTRIAL APPLICATIONS.*

Casting Brass Nuts on Feed-Screws.—Criticism of the general method in vogue for casting brass nuts on the cross-feed screws of the cutting-off lathe is offered by G. C. R.*

In place of a 70 : 30 brass, having an ultimate stress of 28 to 32 tons per sq. in., an elongation of 22 to 28 per cent., and a scleroscope hardness of about 20, it is suggested that an alloy of 82 to 86 per cent. copper, 10 to 14 per cent. tin, 1 to 3·5 per cent. zinc, and a small percentage of lead would give better results.

[The figures given for 70 : 30 brass are much too high for that material in the cast condition.—Note by Abstractor.] It is stated that the other alloy would possess similar physical properties with slightly less elongation. The recommendation is made to add the zinc in a molten condition.

The casting of brass nuts on to feed-screws is not strongly advocated, and preference is given to the making of separate chill-castings, the superior properties of which over those of sand-castings are described.

If direct casting on the screw be practised, the use of a screw slightly larger than the one on which the nut is to be used is advocated, in order that the nut may have sufficient clearance.

Heating the screw facilitates separation of the nut after shrinkage of the former. In such a case, the mould should be of dry sand.

The screw should be quite free from rust or moisture, in order to prevent the formation of blowholes in the nut, and a coating of seal oil and graphite should be thinly and evenly applied.

The writer prefers, however, to produce the nuts separately by casting a bushing in a chill mould, with a metal core, subsequently producing the threads by machining.—F. J.

* *Machinery*, January 18, 1917, vol. ix. p. 442.

ELECTRO-METALLURGY ;
ELECTRO-CHEMISTRY.

CONTENTS.

I.—*ELECTRO-METALLURGY.*

Aluminium, &c., Use of.—An article by P. Askenasy,[*] based on a recently published monograph by R. Richter, deals with the use of aluminium, zinc, and iron as substitutes for copper in the windings of electrical machinery. Aluminium has the advantage that its ordinary oxide coating has sufficiently good insulating properties to save the space which would otherwise be occupied by the insulating covering. It is therefore particularly suitable for winding field magnets. Zinc may also be used, but the wire can only be drawn within certain narrow limits of temperature. Aluminium is suitable for armatures on account of its low centrifugal force. Only copper or iron can be used for commutators. Welded or screwed aluminium joints must be protected by means of insulating material.

The cooling surface of a transformer need only be increased by 6·5 per cent. when aluminium is used instead of copper, or by 17 per cent. when zinc is used. The following relative costs have been worked out:

	Per Cent.
Copper	100·0
Aluminium	96·8
Zinc	150·7
Iron	161·8

It is considered that aluminium will largely replace copper in electrical machinery, even after the war.—C. H. D.

Zinc, Electrolytic.—According to W. R. Ingalls,[†] the largest American plant for the electrolytic production of zinc is that of the Anaconda

Co., which when complete will produce 35,000 tons of electrolytic spelter annually. The ore is concentrated, chiefly by flotation, and is then roasted until the sulphur content is 2 or 3 per cent., mostly as sulphate. The temperature must not exceed 732° C., in order to avoid the formation of zinc ferrite. The roasted residue is leached with spent electrolyte, to which a sufficient quantity of sulphuric acid has been added. A little manganese dioxide, followed by powdered limestone, is added to remove iron, arsenic, and antimony. Lead, silver, and gold remain in the residue, and the only impurities in the filtrate are copper and cadmium, which are precipitated by metallic zinc. After filter-pressing, the solution is electrolyzed with lead anodes and aluminium cathodes. The current density is 20 to 30 amp. per sq. ft. (220 to 330 per sq. m.), and the current efficiency 93 to 94 per cent. The cathodes are stripped every 48 hours and melted.

At the Welland plant, Ontario, dissolving the zinc and electrolyzing the solution are performed in the same vat, the cathodes being enclosed in canvas bags. Other works adopt the same arrangement as Anaconda.

In the author's opinion, the electrolytic refining of zinc is only practicable where power is very cheap, or where other conditions are exceptionally favourable, such as a readily soluble ore, or one high in silver. The recovery of silver from zinc ores, which is only 65 per cent. in the distillation process, amounts to 90 or even 95 per cent. in the electrolytic process. The concentrated ore at Anaconda contains 20 oz. of silver per ton. The spelter is of high purity. Difficulties in this respect were encountered when zinc fume was used to precipitate the cadmium, but the plan is now adopted of running the clear solution through tube mills containing zinc balls. The process is particularly suitable for the fine concentrates obtained by flotation, which are troublesome to treat in retorts.—C. H. D.

II.—ELECTRO-CHEMISTRY.

Brass, Deposition of.—An investigation by A. Höing * shows that solutions containing at least $2KCN : 1CuCN$ exhibit marked polarization in the cathodic deposition of copper ; the reaction is, at least for small current densities, quite reversible for solutions of the composition $1KCN : 1CuCN$. The addition of $K_2Zn(CN)_4$ to $KCu(CN)_2$ also causes polarization, until the deposition potential of the copper rises nearly to that of zinc, when the deposition of brass begins. This is favoured by allowing the cyanide solutions to age, or by heating them, the change being probably due to changes in the colloids, which are present in small proportions. A definite degree of alkalinity is necessary for the production of a pure brass colour.—C. H. D.

Contact Potentials.—A theoretical review of the subject of contact potentials by I. Langmuir * shows that such potentials of large magnitude do exist, even between pure metals in a good vacuum. The evidence is largely derived from a study of the emission of electrons from hot metals and of photo-electric phenomena. Consistent results as to the actual values have been obtained by several independent methods. The methods of experiment and the results obtained are very fully discussed. Richardson has pointed out that with electrons of finite size there may be a difference of potential energy between an electron inside and outside the metal, owing to the work done by the electron against the attraction of its image in the conductor. This is not infinite, as in the ordinary electrostatic theory, because the volume density of the electrification in the ultimate atoms of positive and negative electricity is finite. This shows the necessity of defining strictly the meanings of electric force and electric potential in problems of this character.

It is not necessary to take contact potentials into account when dealing with the electromotive forces of reversible cells only, but when kinetic phenomena such as overvoltage and passivity are dealt with, or where the effects examined are concerned with single potential differences, contact potentials enter into the theory.

The attraction of an electron by a metal surface depends, in the case of the heavier elements, only on the size of the atoms.—C. H. D.

Electroplating Problems.—A paper by G. B. Hogaboom † deals with practical problems in electroplating which still remain to be solved. The list includes a large number of questions of very unequal importance. Little is known as to the influence of the metallic base on the character of the deposit, although certain bases, especially steel and nickel brass, are known to affect the structure of the deposit materially. Rapid analytical methods are needed to determine the free mineral acid in a plating bath containing organic acids. The pitting of nickel deposits, probably due to the primary formation of hydrogen at the cathode, has never been investigated, and the black streaks on nickel when deposited from a single salt solution mechanically agitated, whilst the same solution gives a smooth deposit when used without agitation, are mysterious.

Chromium gives a deposit which is less liable to tarnish than nickel, but the conditions for satisfactory deposition have not yet been found. The same difficulty presents itself in regard to the deposition of a true tin bronze. There are also several problems concerning the efficiency of cyanide baths of different compositions.—C. H. D.

Nickel, Deposition of.—The electrolytic deposition of nickel from chloride solutions has been examined by R. Riedel,‡ with the object

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* *Transactions of the American Electro-chemical Society,* 1916, vol. xxix. p. 125.
† *Ibid.,* p. 369.
‡ *Zeitschrift für Elektrochemie,* 1916, vol. xxii. p. 281.

of avoiding the exfoliation of the nickel, which usually takes place with this electrolyte. Many additions to the bath have been tried, but in all cases without success. Negative results were also obtained by using unsymmetrical alternating current. On the other hand, the defect is completely avoided when the surface of the cathode is well roughened, either mechanically or by etching, or when a thin adherent layer is first deposited from some other electrolyte.—C. H. D.

Nickel-Plating.—A series of laboratory experiments by F. C. Mathers, E. H. Stuart, and E. G. Sturdevant * aim at determining the nickel-plating bath which will give the best deposits at the highest current or voltage. It is found that the purest nickel anodes should be used, as many of the troubles with coloured deposits and with sludge arise from the iron in impure anodes. Pure nickel cathodes, used for this purpose, dissolve irregularly, with much pitting, but the deposit is of very good colour. The anodes may be completely immersed in the solution, being suspended by lead hooks, enclosing bags being used to prevent any disintegrated fragments from reaching the cathode. Magnesium chloride increases the efficiency, and ammonium citrate keeps the electrolyte free from sludge. A suitable bath contains 4 per cent. nickel ammonium sulphate, 10 to 14 per cent. nickel sulphate, 1 to 3 per cent. boric acid, 2 per cent. magnesium chloride, and 0·2 to 0·3 per cent. ammonium citrate. This may be used with a current density of 1·6 amp. per sq. dcm. (14·8 amp. per sq. ft.), which plates a thickness of 0·0025 cm. (0·001 in.) in one and a quarter hours.

A paper on the same subject by O. P. Watts † describes attempts to plate with nickel as rapidly as in the recent Canadian experiments with cobalt. Nickel salts are as soluble as those of cobalt, and the special difficulties arise from the passivity of nickel anodes and the ready absorption of hydrogen by the metal. These difficulties are overcome by using a solution heated to 70° C. The resistance of the solution is then halved, and the current density is increased two or three-fold. The current efficiency, if below 100 per cent. when cold, is raised, and the anode corrosion is greatly improved. The cathode deposit is tougher and less liable to peel than when cold solutions are employed. In the experiments, a current density of 22 to 23 amp. per sq. dcm. (200 to 300 per sq. ft.) have been used with success, giving a deposit in five minutes as thick as that obtained in one and a half hours by the ordinary "rapid" methods.—C. H. D.

Overvoltage.—The previous theories of overvoltage are reviewed by C. W. Bennett and J. G. Thompson,‡ and a new consideration of the question is given. Any chemical reaction in the generation of electricity, if consisting of more than one step, cannot be strictly reversible,

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* *Transactions of the American Electro-chemical Society*, 1916, vol. xxix. p. 383.
† *Ibid.*, p. 395.
‡ *Ibid.*, p. 269.

but must require more energy to re-form the substances than was given out in the original reaction, and it is this irreversibility which gives rise to overvoltage. It is considered that the back electromotive force is due to the accumulation during electrolysis of unstable intermediate products, namely, active (monatomic) hydrogen and oxygen in the case of gases, and monatomic metals in the case of metal overvoltages. These substances are more active than the final products. Active hydrogen, from a tungsten filament, will reduce zinc from its oxide, and cadmium from a solution of the sulphate.

A paper on the same subject by W. D. Bancroft * points to the different results obtained in such reactions as the electrolytic reduction of nitrates when different metals are used as cathodes. High overvoltage and high reducing or oxidizing power do not necessarily go together. Nascent hydrogen from different sources may contain different proportions of neutral monatomic hydrogen.

In the same connection, the latter author discusses † the depolarization of anodes by electric waves. An electrical stress tends to remove any film of absorbed gas, it therefore reduces the overvoltage also at a hydrogen electrode. Some consequences of this, capable of being put to an experimental proof, are suggested.

Measurements of the overvoltage at various electrodes in acid and alkaline electrolytes have been made by E. Newberry.‡ The cathodic overvoltages in normal sulphuric acid and sodium hydroxide have been measured, and the influence of time and of current density determined. Anodic overvoltages are usually much higher than cathodic, being in every case examined 0·4 volt or more. Relatively incorrodible iron alloys, such as chromium steel or " tantiron," give high cathodic overvoltages, and electrodes of these materials might well be used for reduction processes in acid solutions.

As anodes, the best results for moderate oxidations are obtained by using gas carbon at low current densities, iridium being still better for small-scale experiments. In sulphuric acid solutions lead may be used.

The cathodic overvoltages of the metals are closely connected with their position in the periodic system, which is less in evidence when the metal is used as an anode. At high current densities the escaping ionized gas causes a slight fall of the overvoltage, but a much greater fall is produced mechanically by the breaking of the surface. Passivity is attributed to the mechanical resistance of insoluble protective coatings, consisting either of compounds of the metal or of solid solutions of the compounds in the electrode substance.—C. H. D.

Silver Refining.—The effect of various additions to the acid silver nitrate bath has been examined by F. C. Mathers and J. R. Kuebler.§

* *Transactions of the American Electro-chemical Society*, 1916, vol. xxix. p. 301.
† *Ibid.*, p. 309.
‡ *Transactions of the Chemical Society*, 1916, vol. cix. pp. 1051, 1066, 1107, 1359.
§ *Transactions of the American Electro-chemical Society*, 1916, vol. xxix. p. 417.

Tartaric acid is the only agent of much value for this purpose, but the further addition of a small quantity of glue (0·01 per cent. twice daily) makes the deposit smoother and more glossy. Glue and peptone alone do not produce smooth deposits, and metaphosphoric acid renders the deposit hard and non-crystalline, but the bath soon deteriorates. The deposits obtained with tartaric acid are brittle, so that the process is only of use for refining, and not for plating.—C. H. D.

Silver Voltameter.—Further investigations into the sources of error in the silver voltameter have been carried out by G. W. Vinal and W. M. Bovard.[*] By heating the cathode cups in a glazed porcelain covered vessel, electrically heated by an external winding, it is found possible to avoid metallic contamination completely. The weight of a platinum cup is unchanged by heating to 650° C. Cups containing silver deposits lose weight on such treatment, although there is no loss of silver. The results point to the presence of 0·0040 per cent. of impurities on the average when pure electrolytes are used. A source of error which has been previously overlooked is the alloying of silver and platinum, which gives rise to the formation of a layer of platinum black which causes errors in the next determination (by absorbing impurities) if not removed. No marked difference is found between the results with polished and with matt platinum surfaces. The most accurate value for the Faraday is 96,494 coulombs, but the value 96,500 may be safely used for general purposes.

The so-called "volume effect," or the larger deposit obtained in large voltameters used in series with smaller, has been examined by E. B. Rosa and G. W. Vinal.[†] The deviation from unity is greater, the less pure the electrolyte. Intentional addition of filter-paper colloid greatly increases the deviation. The differences are explained entirely by the greater inclusion of colloidal material in the deposits in the larger voltameters. Such measurements serve to determine the purity of the electrolytes.

The same authors [‡] give a detailed specification for accurate work with the silver voltameter, based on the researches of the Bureau of Standards.—C. H. D.

Tin Plating.—It is found by F. C. Mathers and B. W. Cockrum [§] that most of the baths recommended for the electro-deposition of tin give crystalline or spongy deposits, and none of them give a coherent layer. The best contains sodium stannite and thiosulphate, and gives dark deposits which become bright on scratch-brushing, but the bath deteriorates rapidly, and the deposit then becomes black and non-adherent, so that it is useless for practical purposes. The cyanide baths

[*] *Bulletin of the Bureau of Standards*, 1916, vol. xiii. p. 147.
[†] *Ibid.*, p. 447.
[‡] *Ibid.*, p. 479.
[§] *Transactions of the American Electro-chemical Society*, 1916, vol. xxix. p. 405.

give bright deposits, but very little metal is transferred from the anode to the cathode, and the deposit is a mere flash.

A further paper by the same authors * describes experiments with a patented bath containing 5·0 per cent. of stannous chloride, 6 per cent. ammonium oxalate, 1·5 per cent. oxalic acid, and 0·25 per cent. peptone. This gives a thick, smooth, finely crystalline deposit when worked at the ordinary temperature at a current density of 0·4 amp. per sq. dcm. (3·6 per sq. ft.), with occasional stirring.—C. H. D.

* *Transactions of the American Electro-chemical Society*, 1916, vol. xxix. p. 411.

METHODS OF ANALYSIS; PHYSICAL AND MECHANICAL TESTING; AND PYROMETRY.

CONTENTS.

I.—*METHODS OF ANALYSIS.*

Analytical Methods.—An address on some recent progress in analytical chemistry by A. C. Chapman* deals, among other subjects, with the use of organic compounds for the detection and separation of metals. Thus a-nitroso-β-naphthol may be used for several separations besides that of nickel from cobalt, and m-nitrobenzoic acid has been successfully used in the separation of the rare earths. Both dimethylglyoxime and a-benzildioxime are used for the estimation of nickel, the latter being the more sensitive. Dicyanodiamidine sulphate, although less sensitive, has been largely used in the analysis of commercial nickel and nickel-brass. Cupferron, which is the ammonium salt of nitrosophenyl-hydroxylamine, is a very valuable reagent for the separation of iron and copper from other metals.—C. H. D.

Cobalt, Estimation of.—An improved method of estimating small quantities of cobalt in presence of other metals is described by A. D. Powell.† A former method consists in adding a concentrated solution of ammonium thiocyanate to the solution to be tested, and extracting with amyl alcohol, which is coloured blue by cobalt. In presence of ferric iron, the solution has to be again shaken with an alkali to destroy the red colour due to iron, leaving the blue colour due to cobalt. With an insufficient excess of ammonium thiocyanate, the cobalt is only incompletely extracted. A 30 per cent. solution of thiocyanate should be used, two extractions with amyl alcohol then removing all the cobalt. The extract must not be filtered, as filter-paper absorbs much of the

coloured salt. Nessler cylinders are used for comparing the colours. Ferric hydroxide tends to remain in suspension, masking the colour. This is avoided by using sodium pyrophosphate instead of an alkali for removing the iron, the ferric pyrophosphate dissolving readily in an excess of the reagent. The standard cobalt solution also keeps its colour better if kept over a little solid sodium pyrophosphate.

The quantity of substance taken is preferably such as to give a coloration not exceeding that due to 0·5 mg. of cobalt, but the colour is visible when only 0·02 mg. is present.—C. H. D.

Lead, Molybdate Method for.—In the volumetric estimation of lead by means of molybdate, J. F. Sacher * proposes to acidify the lead solution and heat to 70° to 80° C. The supernatant liquid is turbid as long as the lead is in excess, but clears suddenly as the end-point is reached. The point is determined by removing a drop of the solution for examination, the coagulation of the colloidal lead molybdate being observed. The end-point is stated to be sharper than that given by tannic acid as an indicator, and to be independent of the quantity of acetic acid present.—C. H. D.

Molybdenum, Volumetric Method for.—Molybdenum may be conveniently estimated, according to A. S. Jamieson,† by reducing with amalgamated zinc in the usual way, passing the solution through the zinc very slowly, adding iodine monochloride, and titrating with iodate.

The iodine monochloride is prepared by dissolving 10 grms. of potassium iodide and 6·44 grms. of potassium iodate in 75 c.c. of water, adding 75 c.c. of concentrated hydrochloric acid, and 5 c.c. of chloroform, shaking and adding dilute iodate or iodide as required until a faint iodine colour remains. The reduced molybdenum solution, containing not less than 10 per cent. of hydrochloric acid, is run into a flask containing 5 c.c. of the iodine monochloride solution, 25 c.c. of concentrated hydrochloric acid, 5 c.c. of water, and 7 c.c. of chloroform. The solution is well shaken during titration with potassium iodate, until the chloroform layer is permanently coloured. Mo_2O_5 is formed, further oxidation to the trioxide taking so long that it may be neglected, provided that strong sunlight is excluded.—C. H. D.

Nickel Chromium Alloys, Analysis of.—A method of analysis of these alloys is detailed by E. D. Koepping.‡ The sample is prepared for analysis either by taking drillings, or in the case of wire, first cleaning it with emery-cloth, wiping with a clean cloth saturated with alcohol, and cutting into very short lengths.

Silicon.—2 grms. are dissolved in 25 c.c. of a mixture of nitric

* *Kolloid-Zeitschrift*, 1916, vol. xix. p. 276.

† *Journal of the American Chemical Society*, 1917, vol. xxxix. p. 246.

‡ *Metallurgical and Chemical Engineering*, March 1917, vol. xvi. (No. 6), pp. 319–321.

acid one part, hydrochloric acid four parts, together with 10 c.c. water, with the aid of heat on a hot-plate. When solution is complete 0·5 grm. potassium chlorate is added and the solution evaporated to dryness. Take down again with 30 c.c. hydrochloric acid and bake. Cool, take up with 10 c.c. hydrochloric acid and 100 c.c. water, boil five minutes, filter with suction, and wash with hot water and 3 per cent. hydrochloric acid alternately, and finally with water. Ignite, weigh, and evaporate with hydrofluoric acid and one or two drops of nitric acid.

Nickel.—Dilute filtrate from above to 1 litre and take 100 c.c. (0·2 grm.). Dilute to 300 c.c. in a 600 c.c. beaker, add 10 grms. citric acid, neutralize with ammonia, and acidify with 1 c.c. acetic acid. Heat to boiling, and precipitate the nickel as dimethylglyoxime by adding 1 grm. dimethylglyoxime dissolved in 100 c.c. warm alcohol, followed by ammonia drop by drop with stirring, until slightly alkaline. Allow to stand on cooler part of plate ten minutes, stirring occasionally, and filter through a tared Gooch crucible previously dried at 110° to 120° C. Wash with hot water, dry at 110° to 120° C., and weigh as dimethylglyoxime containing 20·316 per cent. nickel (sublimes at 250° C.).

Chromium.—Take 200 c.c. diluted filtrate from silicon, add 10 c.c. sulphuric acid, and evaporate to remove hydrochloric acid. Cool, add a little water, and again evaporate to ensure removal of all hydrochloric acid. Cool, add 50 c.c. water, 60 c.c. nitric acid (1·2 gravity), and boil two minutes. Dilute with 200 c.c. hot water, and when boiling add a strong solution of potassium permanganate until a slight precipitate of manganese dioxide persists. The solution after five minutes' boiling should have a reddish colour from undecomposed permanganate. Decompose the excess with manganese sulphate, cool, filter through an asbestos matt, wash with sulphuric acid one part, water three parts, filtrate having final volume of about 350 c.c. Add excess N/10 ferrous sulphate, and titrate back with N/10 permanganate until pink colour persists one minute.

The chromium value of the permanganate is determined by means of titration against sodium oxalate. The ferrous sulphate is then titrated with permanganate:

(1) In an acid solution previously treated as if it were a sample.

(2) In a solution containing about the same amount of nickel and iron as the sample, previously treated as if it were a sample. The excess permanganate in (2) over (1) is to be subtracted from the amount used in titrating the chromium.

Manganese.—1 grm. sample is dissolved with aid of heat in water 20, nitric acid 5, hydrochloric acid 20 c.c. Cool, add 10 c.c. sulphuric acid, and evaporate to fumes. Cool, dilute, add strong sodium hydrate solution until precipitate persists. Dissolve precipitate with a few drops sulphuric acid and cool. Add zinc sulphate equivalent to 10 grms. crystallized sulphate and 1 grm. zinc oxide, dilute to 500 c.c. and shake. Allow to settle, and decant 250 c.c. through a dry filter.

Transfer to a beaker, heat to boiling, and titrate with N/10 permanganate until a pink colour appears. Add 1 c.c. glacial acetic and boil. The pink colour will be discharged, owing apparently to the liberation of absorbed manganous salt from the precipitate, which now becomes flocculent and settles. Titrate again until pink colour restored.

Iron.—Take 100 c.c. of diluted filtrate from silicon, neutralize with sodium carbonate until precipitate permanent. Redissolve with 1–1 hydrochloric acid added very slowly. Add 1 grm. ammonium acetate, dilute to 300 c.c., and boil vigorously ten minutes. Filter and wash once with hot water. Redissolve precipitate and repeat basic acetate separation. Redissolve precipitate, add slight excess potassium hydroxide, dilute to 200 c.c., boil five minutes, allow to settle, filter, and wash with hot water. Dissolve the ferric oxide precipitate in hydrochloric acid (1–1), and evaporate to small bulk (5 c.c.). Reduce with stannous chloride, dilute with 100 c.c. water, and pour into 400 c.c. water containing 20 c.c. saturated solution mercuric chloride. Add 30 c.c. manganous sulphate solution prepared as follows : 67 grms. manganous sulphate dissolved in 500 c.c. water, 138 c.c. phosphoric acid (1·7 sp. gr.), and 138 c.c. sulphuric acid (conc.) added, and the whole made up to 1 litre. Titrate to a pink colour, permanent for thirty seconds.

Aluminium.—The filtrate from the separation of iron and aluminium above is acidified with hydrochloric acid. Add 15 c.c. saturated sodium phosphate solution, then ammonia until a slight permanent precipitate is formed. Add five drops hydrochloric acid, which should clear up the solution, and then with constant stirring 20 c.c. saturated solution sodium thiosulphate. Heat to boiling, add 20 c.c. solution prepared by dissolving 100 grms. sodium acetate in 200 c.c. acetic acid (1·04 sp. gr.) and diluting to 50 c.c., boil ten minutes, allow to settle, filter, wash with hot water, ignite, and weigh as aluminium phosphate, $AlPO_4$.

Sulphur.—Fuse 2 grms. sample with 15 grms. sodium peroxide in a nickel crucible, applying the heat very slowly. Coal-gas should not be used for effecting fusion, owing to danger of introducing sulphur. Cool, place in beaker, and cover with 30 c.c. water. When the violent action is over, remove the crucible, dilute to 200 c.c., filter, and wash with dilute sodium carbonate solution. Acidify with hydrochloric acid, evaporate to dryness, and bake. Cool, add 20 c.c. hydrochloric acid, and heat till all dissolved. Dilute with hot water and filter. Neutralize filtrate with ammonia, acidify with 1 c.c. hydrochloric acid, heat to boiling, and precipitate with 10 c.c. of a boiling solution of barium sulphate (10 per cent.). Weigh as barium sulphate.

Phosphorus.—Treat 2 grms. as for sulphur and obtain filtrate. Acidify with nitric acid, heat to expel carbon dioxide, add a little ferric chloride solution, ammonia until alkaline to litmus, acidify with acetic acid, boil a few minutes, and filter off precipitated ferric phos-

phate and hydrate. Dissolve in hot 1 1 hydrochloric acid, evaporate
to dryness, redissolve, evaporate to dryness, and filter off silica.
Evaporate to small bulk, drive off hydrochloric acid with nitric acid,
transfer to a flask, add 5 grms. ammonium nitrate and dilute to 50 c.c.
Precipitate with molybdic acid at 80° C. Filter and wash with
ammonium nitrate (5 grms. per litre). Dissolve in 10 c.c. ammonia
(8 per cent.), add 5 grms. ammonium nitrate, dilute to 50 c.c., and re-
precipitate at 80° C. with 20 c.c. nitric acid. The phosphorus may
now be determined in the " yellow precipitate " either by dissolving
in excess standard sodium hydroxide and titrating the excess with
nitric acid or by reprecipitation as magnesium pyrophosphate.

Carbon.—Best determined by mixing with an equal quantity of
red lead, the " blank " of which is known, and burning in oxygen, the
carbon dioxide formed being weighed in the usual manner.—S. L. A.

Percentages, Calculation of.—An account of the arithmetical and
graphical methods of converting atomic weight and volume per-
centages into one another is given by W. Guertler.*—C. H. D.

Phosphates, Crucibles for.—It is found by J. H. Smith † that a new
acid sodium phosphate, $Na_4P_6O_{17}$, which is stable at a bright red heat,
has a remarkably corrosive action on glass, porcelain, and silica vessels.
It also attacks platinum, rendering a platinum crucible very brittle
and porous in a short time. Nickel is rapidly eaten through, forming
nickel pyrophosphate. The salt, which may be called sodium poly-
phosphate, may be useful for decomposing complex minerals.—C. H. D.

Sulphides, Colloidal.—That the formation of metallic sulphide pre-
cipitates is reversible is shown by S. W. Young and W. R. Goddard.‡
A special form of dialyser being used, it has been shown that, for
example, cadmium sulphide may be completely dispersed by the action
of an excess of hydrogen sulphide, and that the precipitate is com-
pletely coagulated when the hydrogen sulphide solution is displaced
by pure water. This process may be repeated indefinitely with the
same result. Other sulphides behave in a similar manner. The
protection of zinc sulphide in a dispersed condition against the coagu-
lating action of hydrogen sulphide increases with increasing pressure.

A detailed study of the influence of hydrogen sulphides and of
electrolytes on colloidal copper sulphide is given by S. W. Young and
R. Neal.§—C. H. D.

**Tin, Lead, and Copper (Babbit Metal), Alloys of Antimony, Analysis
of.**—The following method is given by E. W. Hagmaier ‖ :

* *International Journal of Metallography,* 1916, vol. viii. p. 219.
† *Journal of the Society of Chemical Industry,* 1917, vol. xxxvi. p. 419.
‡ *Journal of Physical Chemistry,* 1917, vol. xxi. p. 1.
§ *Ibid.,* p. 14.
‖ *Metallurgical and Chemical Engineering,* January 1917, vol. xvi. (No. 2), pp. 84–85.

Antimony.—1 grm. is dissolved in 10 c.c. water and 25 c.c. sulphuric acid in an 800 c.c. Erlenmeyer flask. When solution is complete and no black residue remains, remove from hot-plate and cool. Add water 100 c.c., hydrochloric acid 10 c.c., and boil ten minutes to expel sulphurous acid. Cool, add 100 c.c. water, and titrate with potassium permanganate.

Tin.—0·5 grm. is dissolved in 30 c.c. hydrochloric acid, using gentle heat, in a flask as above. A small amount of potassium chlorate may be added if necessary to complete solution. Add water 150 c.c., hydrochloric acid 80 c.c. and a strip of ingot iron, cover and boil for one hour or until all the tin is reduced. Cool quickly, remove the iron, and titrate with 0·1 normal iodine.

Lead.—Place a convenient sample in a 250 c.c. beaker and add 5 to 15 grms. tartaric acid, according to the amount of tin present. Add boiling water 15, nitric acid 3 c.c. When solution complete add 3 c.c. sulphuric acid, and boil till all brown fumes are expelled, and no longer. Cool, add 50 c.c. water, filter off lead sulphate and wash with 2 per cent. sulphuric. Dissolve precipitate in hot saturated ammonium acetate solution, add 2 c.c. acetic acid, bring to the boil, add potassium chromate, and boil until the lead chromate settles well. Filter, wash with hot water, and weigh.

Copper.—Treat a larger sample in the same manner as for tin, to the point where lead sulphate is filtered off. Wash all copper from the lead sulphate, add 2–3 c.c. hydrochloric acid to the filtrate and several pieces of copper-free aluminium, keeping warm. All the copper will be thrown out of solution. Filter off, wash with hot water, dissolve in dilute nitric, and determine by titration or electrolysis.

If by titration, expel all brown fumes, neutralize with sodium carbonate, make slightly acid with 1–3 acetic, and cool. Add 3 grms. potassium iodide (0·5 grm. copper), and stir until all dissolved. Keep solution concentrated. The solution will be brown with a white precipitate. Titrate at once with 0·1 normal thiosulphate, stirring continually. When the brown colour has paled add 10 c.c. starch solution, and titrate until the blue colour disappears.—S. L. A.

II.—*PHYSICAL AND MECHANICAL TESTING.*

Bearing Metals, Tests on.—In a paper read before the American Railway Engineering Association G. H. Tinker * deals with the practicability of various tests on bearing metals. Owing to the difficulties of making friction and wear tests, and the unsatisfactory nature of resilience tests, it is found that compression and tension tests only fulfil

* *Mechanical World*, March 30, 1917, vol. lxi. p. 162.

such requirements as are expected from a rapidly executed test. Hardness tests may or may not indicate the presence of the qualities desired. Hardness accompanied by brittleness and reduction in resilience is not desirable. A metal is suitable for a bearing, not because it is hard, but because, being hard, it is likely to have a low frictional resistance, to wear well, or to be able to sustain pressure without distortion.

The collection of data in order to correlate hardness numbers with other properties is advocated. Figures correlating hardness numbers of bronzes with chemical composition are quoted from a paper by Portevin and Nusbaumer.

The following specifications are suggested for phosphor bronzes:

Grade.	Uses.	Composition.				Elastic Limit in Compression (permanent set of 0·001 in.)	Permanent Set under a Load of 100,000 lb. per Sq. In.	Ultimate Tensile Stress. Lbs. per Sq. In.	Elongation per Cent. on 2 In.
		Cu per Cent.	Sn per Cent.	P per Cent.	Pb per Cent.				
A	For contact with hardened steel discs under pressure exceeding 1500 lb. per sq. in., as used in turntables and centre bearing swing bridge	80	20	<1·0	...	25,000 to 40,000 lb. per sq. in.	0·06 to 0·10 in.	...	...
B	For contact with soft steel at low speeds under pressures not exceeding 1500 lb. per sq. in., e.g. trunnions and journals of bascule and lift bridges	85	15	<1·0	...	19,000 to 23,000 lb. per sq. in.	0·12 to 0·25 in.	...	...
C	For ordinary machinery bearings	80	10	>0·7 <1·0	10·0	15,000 to 20,000 lb. per sq. in.	...	...	...
D	For nuts, gears, worm wheels, and similar parts subjected to other than compressive stress	88	10	<0·25	Zn 2	Not less than 14,000 lb. per sq. in.	Yield point to be recorded	33,000	14

Tensile test specimen to be turned to $\frac{1}{2}$ in. diameter.

Compression test specimens to be cylinders 1 in. high and 1 sq. in. area.

The following stipulations are also given, viz. :

Use of new metals, with the exception of foundry scrap produced on the spot.

Introduction of phosphorus as phosphor-copper or phosphor-tin.

Sulphur not to be present.

Unspecified elements not to exceed 0·5 per cent.

Exercise of due care as regards temperature of melting and pouring and rate of cooling.

Freedom from blowholes, sandholes, porosity, cracks, and other defects.

Rejection of metal if a re-test fails.

Test specimen to be turned from coupons or sinkheads attached to a part of the casting and poured and cooled under the same conditions.

Coupon to be not less than 1 in. in diameter and fed through a gate running the entire length of the coupon.

At least two Brinell hardness tests to be made on each specimen.

Hardness test may be made a requirement for acceptance, should it prove to be a reliable criterion of suitability for a specific use.

Abrasion or friction tests are desirable for white metals, but are neither easily nor rapidly conducted, and the Brinell hardness test is therefore recommended as a suitable expedient.—F. J.

Hardness and Resistance to Wear, Memorandum on Tests of.—An account is given * of Professor Unwin's appendix to the report of the Hardness Research Committee. Moh's scale is described, and its defect in regard to variation in hardness of the standard minerals used is pointed out. Turner's sclerometer test and Marten's modification are described, also the indentation methods of Foeppl, Unwin, and Brinell. The Shore scleroscope is also described.—F. J.

Testing, Methods of.—In an address dealing with scientific problems which call for urgent attention Henry Le Chatelier † points to the desirability of a better method of testing hardness, particularly that of the hardened points of projectiles. The Shore scleroscope, which gives the most useful results, is not independent of the form of the object tested. Our means of determining temperature by both the thermo-electric and the optical pyrometer are subject to several sources of error which have not yet been eliminated.—C. H. D.

III.—*PYROMETRY.*

Cobalt Thermocouples.—The value of cobalt as an element of thermocouples has been examined by O. L. Kowalke,‡ who finds that cobalt wires become coated with a thin film of oxide, which increases in thickness on repeated heating. The wire remains malleable throughout, unlike nickel, the brittleness of which on prolonged heating is

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* *Machinery*, Jan. 11, 1917, vol. ix. p. 401.
† *Comptes Rendus*, 1917, vol. cxliv. p. 205.
‡ *Transactions of the American Electro-chemical Society*, 1916, vol. xxix. p. 561.

well known. Cobalt gives a high electromotive force with the usual base metal elements, and should be useful for the purpose.—C. H. D.

Protection of Thermocouples. For the better protection of copper-constantan thermocouples A. W. Gray [*] recommends leaving the insulating silk winding on the wires until near the end, where one is protected by a glass capillary. The outer sheath is of hard Jena glass, and is cemented into a sleeve soldered to a flexible copper tube. The silk insulation is soaked in hot paraffin before inserting into the tube. The sleeve at the other end of the tube enters a head of paraffined wood which carries the binding screws, and is attached to a brass tube. The cold junction is enclosed in a glass tube, immersed in ice in a vacuum bottle. The wires and junctions are kept dry by a small chamber above the cold junction tube, containing phosphorus pent-oxide. The copper tube is sufficiently flexible to take any position, but protects the couple completely against injury by bending. Only slight modifications are required for platinum couples.—C. H. D.

Thermocouples, Copper-Constantan.—Experiments have been made by T. W. Richards and H. W. Richter [†] to determine whether copper-constantan thermo-elements, used for very accurate temperature measurements, exhibit any hysteresis corresponding with the zero creep of ordinary thermometers. Using a 12-junction thermo-element, it has been found that the transition temperature of sodium sulphate was reproducible to 0.0001 millivolt after heating the element $70°$ C. above that temperature and again cooling. Hysteresis is therefore absent.—C. H. D.

[*] *Bulletin of the Bureau of Standards,* 1916, vol. xiii. p. 283.
[†] *Journal of the American Chemical Society,* 1917, vol. xxxix. p. 231.

FURNACES; FOUNDRY METHODS AND APPLIANCES.

CONTENTS

I.—FURNACES.

Arc Furnaces, Small.—A note by W. M. McKnight [*] deals with the difficulties incident to the use of small arc furnaces, especially for refining steel. The electrical efficiency of such furnaces is sometimes low, and refractories may give trouble. The author, however, erroneously gives the usual temperature of such a furnace as 2500° C., which was pointed out in the discussion as being nearly 1000° too high, the temperature of an electric steel furnace not being necessarily higher than that of an open-hearth furnace. Graphite electrodes, having a higher conductivity than carbon, offer less radiating surface for the same carrying capacity, and in this way compensate for their greater cost.

C. H. Vom Baur [†] describes the Rennerfelt arc furnace, the large flame of which is steady and widely diffused, so that heat is communicated more rapidly to the charge than when the arc is of the thin pencil type. The roof also has a longer life. The voltage at the arc is from 75 to 100, according to size, so that shocks are not dangerous. It is mentioned that the brass industry is now interested in electric furnaces, on account of the difficulty of obtaining crucibles.—C. H. D.

Silica Brick, Uses for and Properties.—The advantages and limitations of silica as a refractory material are compared with other available commercial refractories by W. Gray.[‡]

Magnesia Brick.—Manufactured from grain magnesite imported from Austria-Hungary containing approximately 85 per cent. MgO. The material is carefully selected, crushed, and calcined at approximately 2900° F. (1592° C.). The calcined material is tempered, ground

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[*] *Transactions of the American Electro-chemical Society*, 1916, vol. xxix. p. 492.
[†] *Ibid.*, p. 497.
[‡] *Metallurgical and Chemical Engineering*, February 1917, vol. xvi. (No. 4), pp. 209–216.

with water, made into brick without bond, and burned at a temperature approximating to cone No. 29. Magnesia bricks have a very high fusing point, but soften and lose their coherence at high temperatures. They expand rapidly and uniformly with rising temperature, reaching a maximum at approximately 1500° C. The material is basic.

Chrome Brick.—Manufactured from chrome ore imported from Greece containing approximately 40 per cent. Cr_2O_3, together with alumina, ferrous oxide, and silica.

Although Cr_2O_3 is infusible at temperatures attained in practice, the presence of the impurities above mentioned causes the brick to soften at lower temperatures than magnesia, and they will often, if loaded, prove unreliable at temperatures above 1540° C. Their chief value lies in their chemical inertness, for they are neither acid, basic, reducing, nor oxidizing.

Bauxite Brick.—Manufactured from alumina ore. In calcining the ore excessive shrinkage occurs above 1310° C., reaching a maximum at approximately 1370° C. Water of combination approximating to 30 per cent. of the weight of the ore is driven off. The calcined material is mixed with from one-third to one-sixth part of plastic fireclay and water, moulded into brick, and fired at highest temperatures attainable in the kiln.

Bauxite bricks are basic. Although the fusing point is high, they have the objectionable property of cracking on sudden changes of temperature. By burning at highest possible temperature much of the shrinkage has been eliminated, and bauxite bricks are beginning to be used extensively.

Fireclay Brick.—Fireclays consist of silicates of alumina with impurities in the form of iron, alkali silicates, and water. Free silica in excess of amount required to combine with the alumina will unite with the impurities, act as a flux, and materially lower the fusing point. The alkali content should not exceed 2 per cent. Iron content must be low—5 per cent. will make the brick useless. The brick is baked at about 1370° C.

Silica Brick.—Manufactured from a sandstone or quartzite of sedimentary origin. Certain necessary physical features restrict selection of rock to certain parts of Pennsylvania, Wisconsin, and Alabama. When ground the grains should appear splintery, sharp, and heterogeneous as to form and size, and slightly translucent. It is the physical roughness of the material that gives the brick its strength. Pure quartz, rounded pebbles, or grains of sand prove undesirable, as they will not bind tightly. Suitable quartzite should analyse approximately :

	Per Cent.
SiO_2	97·5
Al_2O_3	1 to 1·5
Other impurities	0·75

Total fluxes should not exceed 3 per cent.

The rock is crushed, subjected to a certain amount of grinding, and then mixed with 2 per cent. of lime added as milk of lime, and ground further. This ground material, but slightly damp, and possessing practically no ductility, is pounded and worked by hand into steel moulds, and finally dried in from ten to twenty hours. The bricks are then stacked in the kiln for burning. During three days the temperature is gradually raised to about 150° C. The temperature is then further raised during the next four days, finally reaching about 1600° C.

Silica brick will analyse approximately :

						Per Cent.
SiO_2	.	.	.	.	.	96·0
Al_2O_3	.	.	.	.	.	0·90
Fe_2O_3	.	.	.	.	.	0·70
CaO	.	.	.	.	.	1·75
MgO	.	.	.	.	.	0·14
Alkalies	.	.	.	.	.	0·39
						99·88

They are straw-coloured, having a coarse crystalline fracture. They are the ideal brick to use where a high and constant temperature is to be encountered, and where chemical action of the slag is not detrimental. Great care should be exercised in bringing silica bricks up to their working temperature slowly and evenly. The abuse the bricks will stand after proper treatment in the original firing is wonderful. They retain their shape and refractoriness almost to point of fusion, and are capable of supporting loads of 75 lb. per sq. in. or more at temperatures well over 1500° C. In this respect they are superior to magnesia or chrome brick. Silica brick should show a good expansion on first burning, and a relatively small one thereafter.

Attention is called to special uses for silica brick. Its use in open-hearth furnace construction is increasing. So favourably have they behaved that many open-hearth plants are making all their chequer work of silica brick. Other uses are for boiler furnaces, coke-ovens, lime-kilns, cupolas, and gas-retorts. The advantages and properties of silica are just beginning to be appreciated.—S. L. A.

II.—FOUNDRY METHODS AND APPLIANCES.

Aluminium Swarf, Recovery of Metal from.—The treatment of large quantities of very fine waste from the machining of aluminum and its alloys is dealt with by W. J. May.*

Scrap metal should be collected in a clean state, keeping pure metal from alloy, and excluding all brass and bronze waste. After drying,

* *Mechanical World*, December 22, 1916, vol. lx. p. 313. See also *Bureau of Mines, Bulletin* 108.

iron should be separated in a magneting machine. Owing to the low specific gravity and bulkiness of the metal, large crucibles (iron or plumbago) are necessary. The temperature of the furnace should be under control. Clay liners should be supplied to plumbago crucibles in order to protect the latter from the destructive action of the flux used.

Iron crucibles are used in the process in which no flux is used, and should be given an internal wash of a plumbago and clay mixture, in order to protect the iron from the action of the aluminium and zinc.

In the first process, a pool of metal should be prepared by melting large pieces of scrap in an iron crucible, subsequently adding fine stuff from time to time, continually kneading the mass into a pasty condition. Dross accumulates on the surface, and should be removed by skimming just before pouring.

Oak stakes or iron rods may be used for kneading. The amount of metal recovered varies from 40 to 60 per cent.

In the second process, clay-lined crucibles are used, and the fine aluminium waste is introduced after mixing it with 20 to 50 per cent. of its weight of a flux consisting of 85 per cent. common salt and 15 per cent. fluorspar. These proportions may be varied, and a little fine charcoal may be used if necessary.

The mixture is charged in small quantities and pressed together as it becomes pasty. When full, the temperature is raised to 1600° F., and the flux melts and rises to the surface and is skimmed off before pouring the metal into bars. The amount of metal recovered by this process varies from 50 to 80 per cent.

Recovered metal from the first process must be remelted with liberal fluxing of powdered zinc chloride introduced by means of a plunger-mixer. Dross should be skimmed off into water, and the parts holding recoverable metal separated, dried, and again treated.

The guiding principle in the first process is to break through the films of oxide separating the individual globules of metal by mechanical means, and that in the second process to secure the same result with the aid of flux.

The coating of oxide on melted scrap from aluminium-zinc alloys is less difficult to remove than that from commercially pure aluminium. —F. J.

Brass-Casting Problem.—Details concerning the production of brass castings of special design are discussed.* Advice is given regarding composition of metal, thickness of metal between and around cores, temperature to which cores should be heated, and nature and design of cores. In case of using " chill " cores, a light coat of clay-wash, made of clay and plumbago mixed in water, is recommended.—F. J.

* *Machinery*, January 1, 1917, vol. ix. p. 443.

Bronze Cloth-Printing Roll, Moulding of.—The dimensions of cloth-printing rolls, weighing approximately 1 ton, are given by J. P.*

The mould is made in dry sand from a split pattern, and is poured on the joint from one end. Details of the preparation of the core, mould facing, &c., are given. A good head, at least 18 in. above the highest point of the casting, should be used. Rate of pouring should be fairly fast, and temperature medium. The metal is best melted in a crucible, and great care is necessary in mixing and melting.—F. J.

Foundry Practice, Continental.—In a paper which was read to the London branch of the British Foundrymen's Association the methods in vogue in German foundries are described by H. G. Barrett.† Under "Training Methods" it is pointed out that boys are selected to learn the trade of a moulder, because they appear to be adapted for that particular branch of engineering industry.

At Nuremberg there is a school at which boys attend, and are instructed in the use of tools and mechanical appliances before entering the factories.

At the Siemens and Schuckert works boys must first go into apprentice workshops, and during the whole of their apprenticeship they are compelled to attend school, fifteen hours per week being taken for this purpose from their working time.

In towns where there are many small firms, there is a system of co-operation between employers and technical centres.

Business methods of German firms are described, and the interiors of foundries and methods of working.

In a large brass foundry at Düsseldorf it was the rule to dry all moulds for castings of 56 lb. and over. At the Chemnitz Metal Factory, castings are examined for internal gas-holes, non-metallic enclosures, &c., under X-rays. In this way defective castings could be picked out and machinery operations saved.

Some special appliances are described and illustrated, *e.g.* a chamber for making phosphor copper in use at Chemnitz. The mixing pot is placed in a chamber cylindrical in shape with a chimney for taking off fumes. Sticks of phosphorus are placed in the mixing pot, the receiver of which may be closed by lowering a ball into position. Copper is then poured into a chute communicating with the receiver, which is then closed by lowering the ball; the pot is given an oscillatory movement, which is facilitated by it being suspended by handles on bearings at each side of the chamber. The clay stopping at the tapping hole of the pot is then broken away, when the phosphor copper passes down a discharge chute into ingot moulds.

A phosphor-tin ingot mould of cast iron is described, which is fitted with a perforated plate on top, above which is a cover fitted with a receiver. Phosphorus is passed through the holes in the perforated

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* *Mechanical World*, June 30, 1916, vol. lix. p. 312.
† *Ibid.*, February 25, 1916, vol. lix. p. 88.

plate, the cover placed in position, and tin poured into the receiver. Vent-holes and receiver are then closed up, and the tin having run through the holes in the plate, dissolves the phosphorus in the lower chamber forming the ingot mould, and there the alloy is allowed to solidify.

Another arrangement for making phosphor-tin is described, in which molten tin and phosphorus are mixed in a basin covered by a tight-fitting dome. The vessel is caused to revolve to effect thorough mixing. One of the spindles on which the vessel revolves is made hollow and fitted with a spring-seated valve to allow of the escape of gas and vapour.—F. J.

Molten Brass, Weighing of.—A method of weighing molten metal in crucibles is illustrated and described by E. Tonkin.* A steel stand, the sides of which are notched at the top to support the carrying bar from which the tongs holding the crucible are slung, is placed on a travelling weighing machine, weighings being taken with the crucible empty and afterwards with it full of molten metal.

An example is given as follows :

Weight of charge . . . . 645 lb.

	Crucible.	Weight of Crucible, Tongs, Bar, and Stand.	Weight of Molten Brass, Crucible, Tongs, Bar, and Stand.
		Lb.	Lb.
First		150·0	312·0
Second		153·0	309·5
Third		154·0	310·0
Fourth		156·5	311·5
Total		613·5	1243·0

Weight of molten metal . . . 1243·0 – 613·5 = 629·5 lb.
Loss . . . . . . 645·0 – 629·5 = 15·5 lb.
Melting loss . . . . . 2·40 per cent.

<div align="right">F. J.</div>

Non-Ferrous Castings in a Railway Foundry.—The practice followed in the foundry operated by the Pennsylvania Railroad Co., at Altoona, Pa., is described by E. L. Shaner.†

This plant has to furnish all the brass castings, journal bearings, metallic and other non-ferrous metal appliances for all cars, locomotives, &c., operating on the Pennsylvania lines east of Pittsburgh. The foundry is in operation twenty-four hours each day, and maintains a daily output of 30 tons of non-ferrous castings, in addition to white metal ingots and copper.

Owing to the rapid deterioration of steel doors in passenger cars, attention was paid to producing doors in aluminium because of its

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* *The Foundry*, January 1917, vol. xlv. p. 20.
† *Ibid.*, p. 1.

light yet strong construction, its resistance to rust, and the ease with which it can be converted to other uses if distorted in a wreck, or replaced by one of later design.

The first difficulties encountered, including cracks and warping, were successfully overcome. Illustrations of the doors are given and details of moulding explained. Every precaution has to be taken to prevent uneven stresses arising from the shrinkage of the metal when cooling, chills being therefore extensively used, about seventy for each casting.

The metal is poured from two ladles simultaneously into gates at each corner at the upper end of the mould. In order to eliminate the disastrous strains which would be caused by the rigidity of this end of the mould thus enforced by the position of the gates, an arrangement is provided for draining the gates empty as soon as the mould is filled.

The patching of a broken casting is described, and other points in connection with the production of miscellaneous castings.

Moulding machines are used for most of the work, whilst practically all of the patterns and pattern plates are made of brass or aluminium.

All castings weighing less than 110 lb. are cleaned in a rumbling barrel, larger ones being cleaned by pneumatic hammers.

The melting equipment consists of thirty-three pit furnaces and two Piat furnaces, twenty-two of the former being arranged in a circle round a single stack. One of the Piat furnaces has been converted from coke to gas firing.

A special ingot mould tilting-stand for facilitating the handling and cooling of ingot metal is described.—F. J.

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